Report No. CG-D-62-77

(12)

ADA047513

FIRE PERFORMANCE OF INTERMODAL SHIPPING CONTAINERS

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October 1977

Final Report

Document is available to the U.S. public through the
National Technical Information Service,
Springfield, Virginia 22161

Prepared for

DEPARTMENT OF TRANSPORTATION
UNITED STATES COAST GUARD
Office of Research and Development
Washington, D.C. 20590

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Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
18 19 USCG-D-62-77		

4. Title and Subtitle	5. Report Date
6 FIRE PERFORMANCE OF INTERMODAL SHIPPING CONTAINERS.	11 October 1977
	6. Performing Organization Code
	8. Performing Organization Report No.
7. Author(s)	14 CGR/DC-23/77
10 Randall Eberly	
9. Performing Organization Name and Address	10. Work Unit No. (TRAIS)
U. S. Coast Guard Research and Development Center Avery Point Groton, CT 06340 12 62p.	11. Contract or Grant No.
	13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address	9 Final Report,
Department of Transportation United States Coast Guard Office of Research and Development Washington, DC 20590	14. Sponsoring Agency Code

15. Supplementary Notes

Performed at the Research and Development Center's Fire and Safety Test Detachment, Mobile, Alabama.

16. Abstract

During the week of 19 July 1976, a full-scale fire test series was performed at the U. S. Coast Guard Fire and Safety Test Detachment to examine the potential fire hazards of intermodal shipping containers. The three-part test series was conducted on Little Sand Island in Mobile Bay, Alabama. The first sequence of tests were planned to evaluate whether a fire originating within a sealed intermodal container could burn through the container shell. The second task of the test series was to determine the effects of an exterior pool fire exposure on a single level of containers, and the final task was to evaluate the effects of an exterior pool fire exposure on a stack of containers.

Standard 8 foot by 8 foot by 20 foot steel, aluminum and fiberglass-reinforced plywood shipping containers were tested.

The interior fire tests utilized two 30-pound wood cribs constructed of white fir and 2 gallons of naptha as a fuel source. For the exterior fire tests, a 29 x 24 foot steel test pan containing JP-5 was constructed beneath the container stack. Standard container stacking and lashing arrangements were used for all tests.

17. Key Words	18. Distribution Statement
fire hazards, container, intermodal container, fire endurance	Document is available to the U. S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
UNCLASSIFIED	UNCLASSIFIED	61	

Form DOT F 1700.7 (8-72) Reproduction of form and completed page is authorized

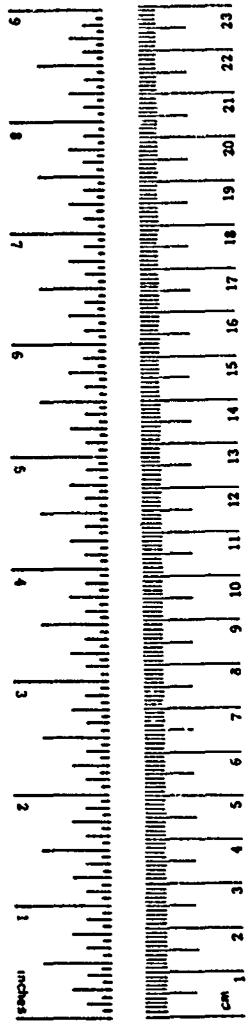
408 730 LB

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

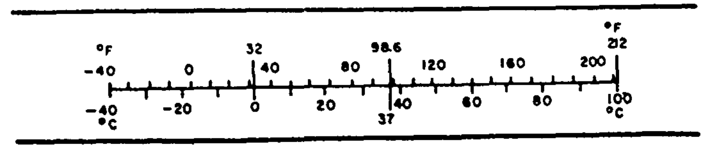
Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10 286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGEMENTS

This test series is one facet of an on-going research and development program conducted by the United States Coast Guard. The ultimate mission of this program is to implement newly developed technology and progressive engineering techniques into the Commercial Vessel Safety Program, thereby providing an optimum means to insure the safety of life at sea.

The following individuals, representing a highly qualified group of experts from the container shipping industry, provided invaluable assistance in this particular test series:

M. H. ALLEN, U. S. Coast Guard

CAPT M. W. ALLEN, Marine Container Equipment Certification Corporation

P. W. SHAHANI, Sea-Land Service, Incorporated

RADM C. P. MURPHY (U.S.C.G. RET), Sea-Land Service, Incorporated

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1.0 INTRODUCTION

1.1 Background

The transport of commodities stowed in intermodal shipping containers is a technique adopted by the merchant marine industry well over two decades ago. It differs from the break bulk shipment of cargo in one important aspect. Containerized cargo stowed in dry van containers can be rapidly transferred from truck to rail or from truck to container vessel and, while being transported, the cargo requires no additional protection from the weather. This permits the rail shipment of containers in trailer-on-flat-car or container-on-flat-car configurations, and also permits the on-deck stowage of containers aboard container vessels.

From a fire protection consideration, the on-deck stowage of containerized cargo is a unique situation. The large quantity of cargo that is stowed on the deck of a container vessel increases the amount of combustibles that the installed fire protection systems must contend with, and the containers also form a barrier which may prevent the effective application of fire-fighting agents. If a cargo fire occurs within a container stack, an accurate prediction of the resulting scenario cannot be made on the basis of shipboard container fire experience to date. Since the advent of container shipping, there has been only one major casualty aboard an American flag container vessel. The collision of the SS C.V. SEA WITCH with the SS ESSO BRUSSELS on 2 June 1973 resulted in the near total destruction of all 285 containers and cargo stowed on the deck of the SEA WITCH. This fire did not initiate within the container stack, but spread from the pool fire of more than one million gallons of Nigerian crude oil surrounding the container vessel which had leaked from the ruptured cargo tanks of the SS ESSO BRUSSELS. The heat flux the containers experienced from this exposure was in excess of that normally produced in laboratory furnace tests used to determine the fire endurance of shipboard materials. It is doubtful that a radiation level of this extreme could ever be produced in a casualty involving only a deck stow of containerized cargo. Because of the lack of past experience, it is essential that the containerized freight concept be evaluated from a full-scale experimental viewpoint to determine credible fire situations which may be directly caused or influenced by some particular aspect of containerization. Because of the variety of cargo types and configurations stowed within intermodal containers, it is not practical to also evaluate the effects of various cargos on flame spread in this study. It is realized that incompatible or oxygen-generating materials will add undesirable aspects to a fire situation.

By evaluating routine transport configurations used for intermodal container shipping, several potential fire scenarios can be predicted. Typical container stowage arrangements indicate that an interior fire may occur as a result of shifting cargo within a lashed container. A second scenario can be visualized, where due to a flammable fluid leak or other source, a container stack is exposed to a limited exterior fire source. If a container stack is exposed to either of these two credible fire situations, an estimation of the potential flame spread through the remainder of the container load is necessary.

1.2 Purpose

The purpose of this test series is to evaluate intermodal shipping containers to determine their potential effects on flame spread. This evaluation is comprised of the following specific tasks:

a. Comparison of steel, aluminum, and fiberglass-reinforced plywood container panels to determine if greater fire resistance is offered by one particular means of construction.

b. Determination of any general feature of construction of container frames or hardware that may affect the overall fire resistance of a container.

c. Determination of whether a credible interior fire is capable of burning through a closed intermodal shipping container.

d. Determination of the effects of a limited exterior pool fire exposure on intermodal shipping containers.

e. Determination of whether the wooden floorboards used in intermodal shipping containers adversely affect the spread of flame in a container stack.

f. Determination of whether typical container stacking and lashing arrangements offer adequate container stack stability under fire conditions.

2.0 TEST PROCEDURE

2.1 Test Facility

The container test series was conducted at the Coast Guard Fire and Safety Test Detachment in Mobile, Alabama. Because gantry cranes or other appropriate container-lifting apparatus could not be practically erected, the tests were not conducted aboard one of the Test Detachment vessels. A gravel test pad of approximately 3600 square feet was constructed on Little Sand Island, adjacent to the T/V ALBERT E. WATTS. A 29 by 25 foot simulated hatch cover was constructed on the test pad consisting of welded steel plates. Steel coamings were also welded along the perimeter of the mock-up hatch cover to form a ten-inch deep fuel pan for use during the pool fires. Two steel I-beams with six-inch flanges were fitted with bottom-stacking fittings and pad eyes (Figure 1) and centered in the fuel pan to act as a base for the container stack.

2.2 Fuel Source

a. Internal Fire Tests - Standard wood cribs weighing 30 pounds ± 5 percent constructed of 45 2-inch by 2-inch by 15-inch pieces of white fir were used as Class A fuel source. Two wood cribs were stacked vertically over a 13-inch by 13-inch by 4-inch steel pan (Figure 2) containing two gallons of naptha. In Tests 1 through 3, the fuel source was located at the center point of the container floor. Test Number 3a was conducted with the wood crib and naptha plan located five inches from the starboard or curbside rear corner of the aluminum container.

b. External Fire Tests - JP-5 was used as a fuel source for all external exposure tests. Several gallons of naptha were used to prime the JP-5 for easier ignition.

2.3 Ignition Method

For the internal tests, sufficient lengths of fuse cord were run from the naptha pan at the base of the wood crib to the exterior of the container. The fuse cord was then manually ignited from a safe distance.

2.4 Instrumentation

The Fire and Safety Test Detachment instrumentation van was used for this test series. To facilitate the connection of all necessary wiring and electrical power supply circuits, the van was loaded on one of the Test Detachment LCM's which was then moored on the island adjacent to the test site.

For all of the interior fire tests, internal temperatures, oxygen, carbon monoxide, and carbon dioxide levels were measured and recorded. On the external exposure tests, only interior air temperatures were recorded. Specific locations of thermocouples and gas sensors are listed in Section 4.2. The thermocouples and gas sensor tubes were led into each container through small holes drilled in each container door. The openings were then sealed with a high-temperature caulking material (Figure 3). Type K, ungrounded, inconel-sheathed 1/8-inch diameter thermocouples were used for all tests.

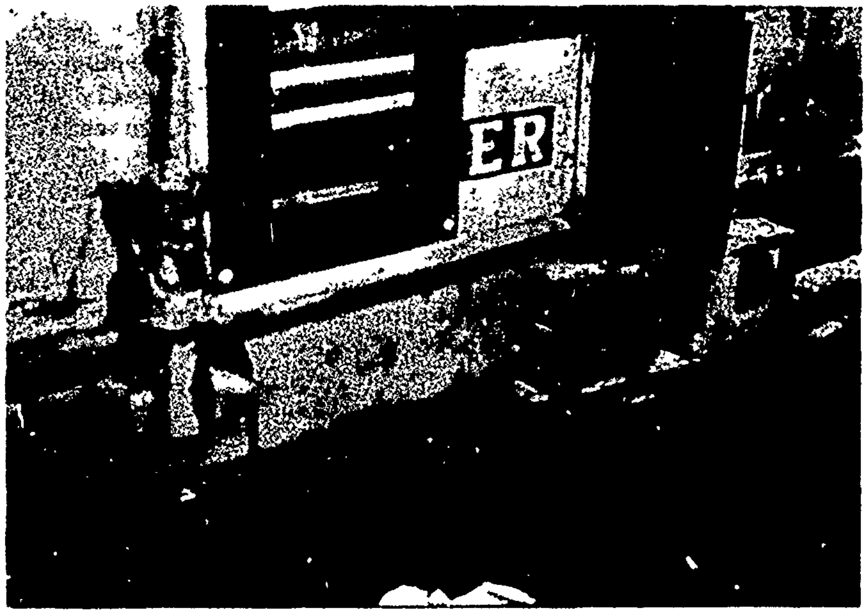


Figure 1 — Container Stack Base Fittings

Figure 2 — Wood Crib Fuel Source

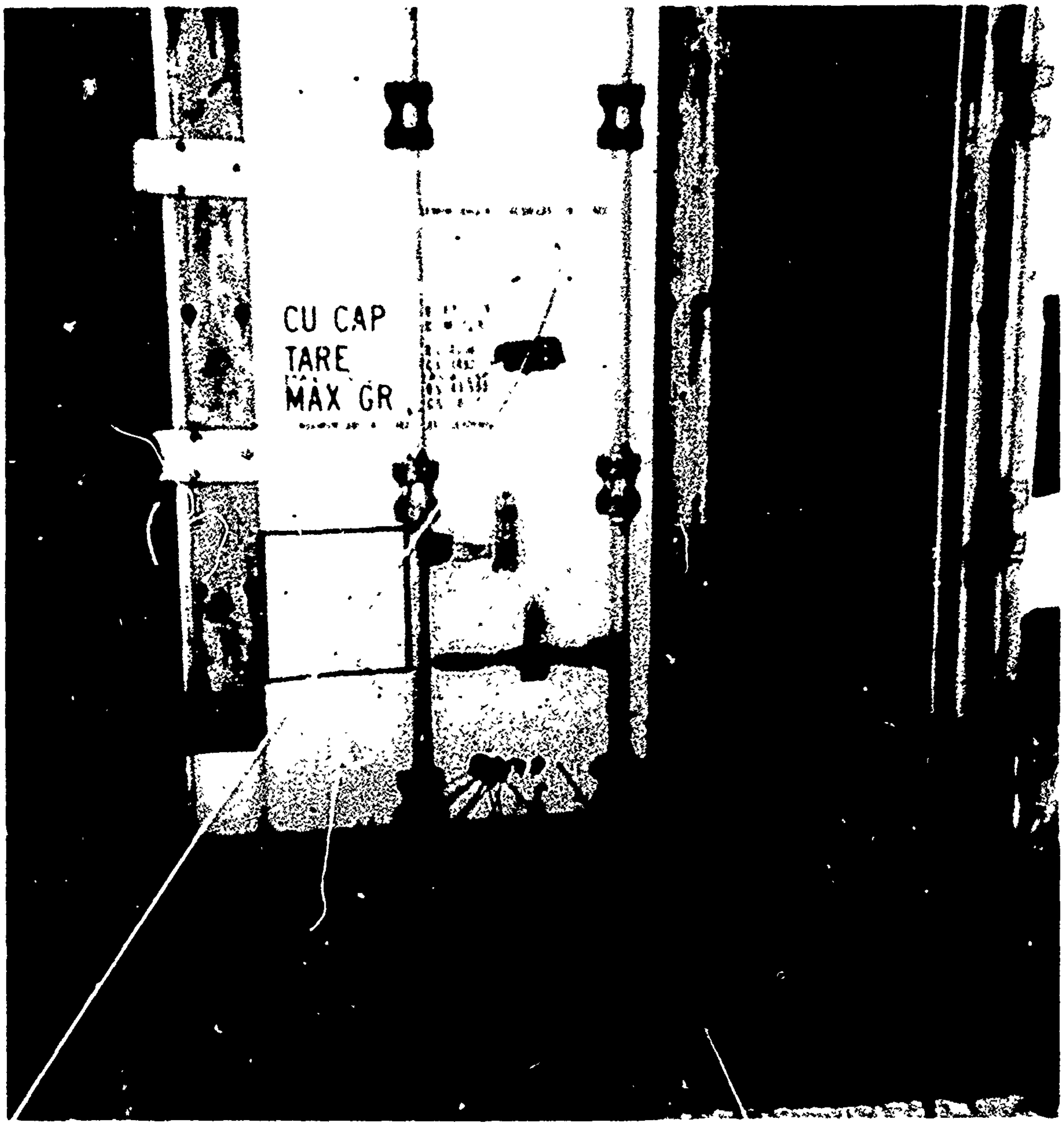


Figure 3 — Instrumentation Lead-ins

Oxygen concentrations were measured using a thermomagnetic oxygen analyzer with a range of 0 to 25 percent $O_2 \pm 0.4$ percent. Carbon monoxide concentrations were measured with a Luft-type infrared analyzer with a range of 0 to 10 percent CO $\pm$ 0.2 percent. Carbon dioxide concentrations were also measured with a Luft-type infrared analyzer with a range of 0 to 50 percent $CO_2 \pm 1.0$ percent. All instrumentation was fed into an analog-to-digital converter. The output of this machine was recorded on both printed paper tape and paper punch tape. The punch tape was used as input for a computer which plotted all data as engineering units versus time.

3.0 CONTAINERS

Figure 4 shows an exploded view of a typical intermodal van-type container. Containers are structurally supported by frame components, consisting of two bottom rails, two top rails, and two end frames. The frame components are usually high tensile strength steel or extruded aluminum alloy. Constructed about the container frame are two side panels, a front end panel, rear doors, a base floor, and roof. Side and end panels consist of varying materials, usually specified by purchaser's requirements. The containers evaluated in this series involved four basic types of panels. Figure 5 shows a cutaway view of steel fiberglass-reinforced plywood (commonly called FRP), exterior post-aluminum, and interior post-aluminum panels. Container doors are constructed of the same materials as the container side panels, or they may be a composite material called "plymetal." Plymetal doors are constructed of a plywood core with aluminum or galvanized steel sheeting on both exposed surfaces. Container floors are generally constructed of laminated hardwood floorboards supported by cross-members which join the bottom siderails. The floorboards are generally butted to one another by either tongue or groove or ship lap constructions. Container roofs are generally constructed of materials similar to the container side panels.

All joints formed by the connection of a frame member to a panel are sealed by caulking or a gasket to provide water tightness and corrosion resistance.

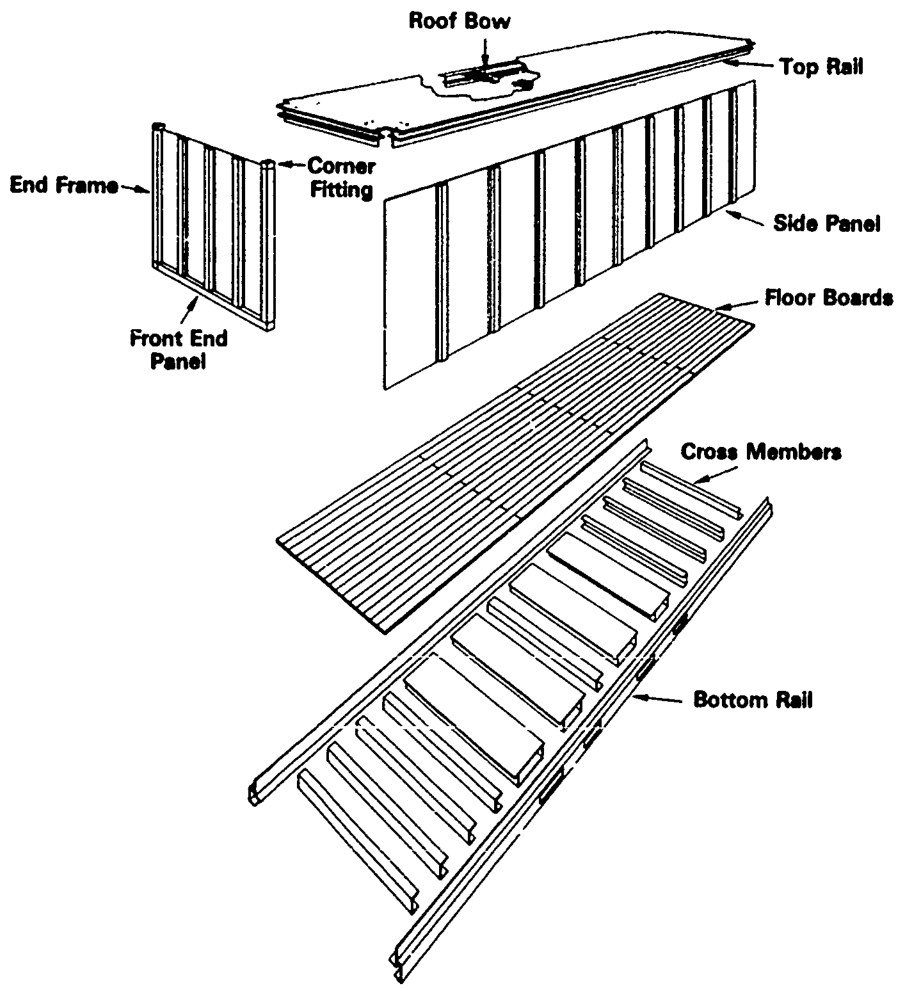


Figure 4 — Intermodal Shipping Container Van Type

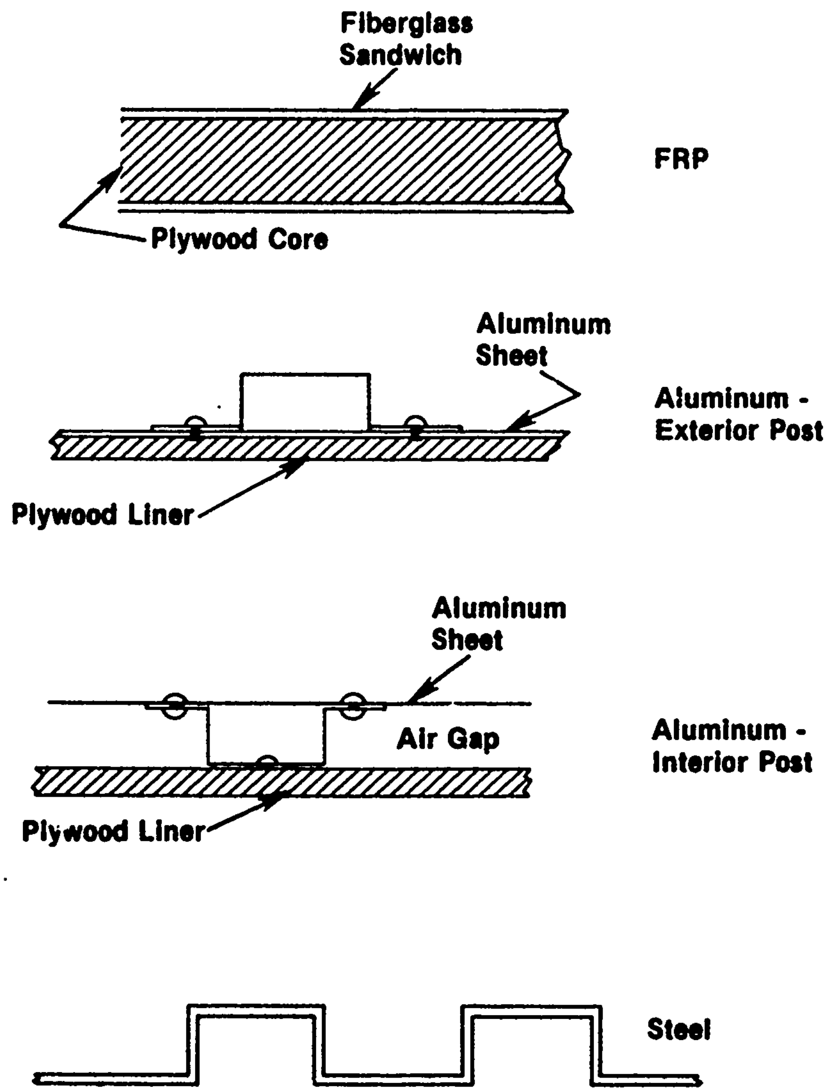


Figure 5 — Typical Container Panel Constructions (Cross Section)

4.0 INTERIOR FIRE TESTS

4.1 Theory

The single factor capable of regulating combustion of fuels within a sealed container is the amount of available oxygen. Assuming no leakage, the maximum quantity of air in one of the 20-foot test containers is approximately 1,280 cubic feet. A loaded container will naturally have less than 1,280 cubic feet of air available for combustion. Therefore, to simulate a maximum or worst case test situation, it was decided to test containers filled with as little cargo as possible. Because of the variety of cargo normally stowed in containers, it was also decided to utilize both a Class A and a Class B fuel.

Calculations using a combustion engineering formula[1] indicated that the wood cribs to be used as a fuel source would require 92 cubic feet of air for the complete combustion of each pound of wood. Therefore, an approximate 14-pound weight loss could be expected. Because the airtightness of the test containers could not be guaranteed, it was decided to use two 30-pound wood cribs per test. The conglomerate fuel source including a steel pan containing two gallons of naptha occupied a volume of approximately three cubic feet.

The containers used for the interior fire tests were containers which were removed from service because of their overall deteriorated condition; however, they were determined to be structurally adequate for these tests. Minor defects such as broken hinges, torn door gaskets, and dented frame rails were noted on the containers. No special repairs or sealing materials were employed to render the containers overly airtight. In fact, because of their condition, these containers were probably less airtight than containers in normal service. Table 1 is a summary of data for the interior fire tests.

4.2 Thermocouple Locations

For Tests 1 through 3a, 15 thermocouples were placed at various levels throughout each container. Two thermocouple "trees" were spaced approximately ten feet apart on the centerline of the container. Five thermocouples were mounted on each tree; one on the floor, one on the ceiling, and one every two feet in between. One thermocouple was placed in the center of the wood cribs, and one thermocouple was placed at the approximate midpoint of each side panel.

4.3 Discussion of Interior Fire Tests

Detailed test data for Tests 1, 2, 3, and 3a are listed in Appendix A. All four interior fire tests produced similar results. Before flame spread to adjacent containers could occur, the interior fires became oxygen regulated, thereby ceasing combustion.

As noted in Section 4.1, the amount of available air in a sealed test container is theoretically sufficient for the combustion of a maximum of 14 pounds of wood. Test 1 involved a steel container with four high-level vents (Figure 6). With this additional natural venting, it was predicted that combustion of more than 14 pounds of wood might occur. A 13-pound weight loss of

INTERIOR FIRE TESTS

TABLE 1 - SUMMARY OF DATA, TESTS 1 THROUGH 3a

Test Number & Container Type	Time	O_2 Conc.	CO Conc.	CO_2 Conc.	Ceiling Temp.	Wood Crib Temp.	Weight Loss, Wood Crib
Test #1 Steel	2:00	21%	.2%	.5%	56°C	38°C	13 lb.
	4:00	21%	.2%	.5%	65°C	280°C	"
	8:00	15%	.3%	6.2%	173°C	498°C	"
	10:00	16%	.4%	5.0%	132°C	255°C	"
	12:00	16%	.4%	5.0%	120°C	170°C	"
Test #2 FRP	2:00	21%	.2%	1.2%	40°C	38°C	25 lb.
	4:00	21%	.2%	1.2%	40°C	190°C	"
	8:00	20%	.2%	1.2%	225°C	340°C	"
	10:00	16%	.5%	3.0%	110°C	425°C	"
	12:00	15%	1.0%	4.0%	100°C	340°C	"
Test #3 Aluminum	2:00	21%	.2%	.4%	58°C	38°C	10 lb.
	4:00	21%	.2%	.4%	68°C	435°C	"
	8:00	14%	.4%	6.0%	142°C	582°C	"
	10:00	16%	.3%	3.0%	118°C	160°C	"
	12:00	17%	.35%	4.0%	100°C	110°C	"
Test #3a Aluminum	2:00	21%	.2%	1.0%	55°C	220°C	7 lb.
	4:00	21%	.2%	1.0%	220°C	540°C	"
	8:00	13%	.8%	8.7%	230°C	310°C	"
	10:00	15%	.5%	5.5%	165°C	198°C	"
	12:00	16%	.5%	4.5%	130°C	175°C	"

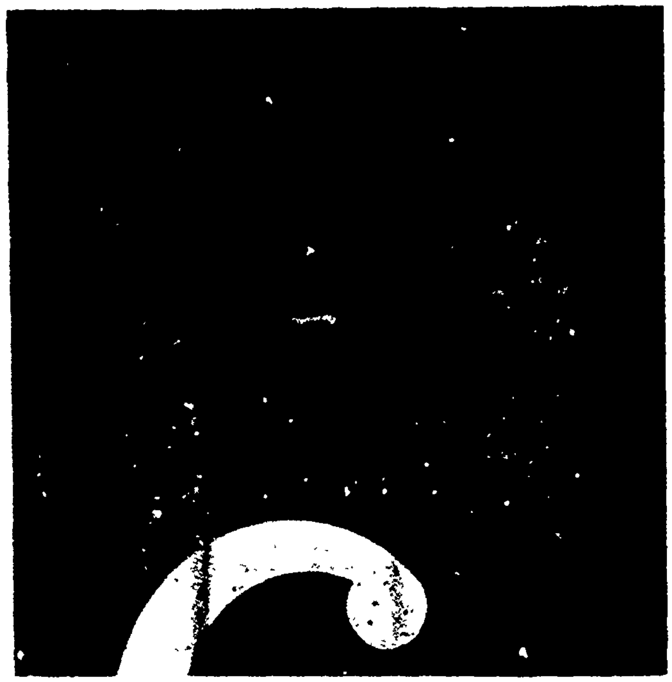


Figure 6 — Natural Venting on Steel Container

Figure 7 — Charring of Plywood Liner, Test 3a

the wood crib was observed in the test. During the test very little evidence was seen to indicate the container contents were burning. Very minute traces of smoke were noted emanating from various points of the container. The only apparent effects of the wood crib fire on the container was a circle of approximately 18 inches in diameter on the ceiling of the container where the paint had burned off.

The FRP container used for Test 2 was not vented. In the test, a weight loss of 25 pounds occurred. It is felt that warped floorboards allowed the leakage of sufficient quantities of air to permit glowing or deep-seated combustion of the wood crib. Additionally, it was noted that the FRP panel joints were sealed with a caulking material which decomposed from the heat of the fire. The deterioration of this material may have allowed additional air leakage. There were two noted effects of the test fire on the FRP container. As in Test 1, a slight darkening of the ceiling occurred directly above the wood crib, and secondly, the heat of the fire caused styrene boil-out from the woven roving on the container roof panel during the test.

Test 3, involving an aluminum container, produced similar results to Test 1. Prior to this test, it was predicted that the heat flux from the wood crib test fire would be sufficient to cause melting of the aluminum roof panel. During the test, the roof panel deformed inwardly approximately one and one-half inches directly over the wood crib. Apparently, the thermal conductivity of the aluminum roof panel greatly helped to dissipate the heat to the atmosphere thereby preventing its melting. Table 2 is a comparison of temperatures of the roof panels for each type of container measured at the peak of combustion.

TABLE 2

ROOF PANEL TEMPERATURES

	FWD THERMOCOUPLE TREE	AFT THERMOCOUPLE TREE
Aluminum	140°C	140°C
FRP	240°C	240°C
Steel	170°C	180°C

Test 3a was conducted to determine if moving the wood crib to a corner of the container would produce any effects not observed in Test 3. The relatively undamaged container used for Test 3 was again used for this test. The wood crib was situated five inches from the curbside rear corner of the container. The only additional effects noted in this test were charring of the plywood liner and melting of the overhead door gasket. Figure 7 shows the extent of charring on the plywood liner.

In a report dated April 1973,[2] the Netherlands Ship Research Centre reported on a similar test series conducted in the Netherlands. In those tests, almost identical results to those produced in this study were obtained for a ventilated steel container and an FRP container. In the Netherlands Ship Research Centre tests, wood crib weight loss of approximately 12 pounds were recorded in all cases. A second report dated November 1974[3] discusses the results of tests conducted on aluminum containers. As a result of both test series, the Netherlands Ship Research Centre concluded that, "a fire inside a container (regardless of the cause) will not inflict very much harm on the container in question and certainly not on adjacent containers."

5.0 EXTERIOR FIRE TESTS

5.1 Single-Level Exposure - Theory

In Section 1.1 it was stated that the two credible fire scenarios developed for intermodal container transport included exposure from an exterior fire source, either a flammable liquid leak or possibly another source such as a fire in the container vessel's superstructure. Tests 4 and 5 were designed to simulate the exposure of the top level of a container stack in such a manner that the underside of the containers would have no effect on the test results. This was accomplished by flooding the test fuel pan with water to raise the fuel level above the container floors. Originally, several tests of varying duration were planned. The burning time could be regulated by the amount of fuel floated on the water surface. Previous test experience has shown that the JP-5 will burn off at a rate of approximately one-tenth of an inch per minute.

Since little damage was incurred in the internal fire tests, the original three containers used for Tests 1 through 3a were stacked as shown in Figure 8 and used for Tests 4 and 5.

5.2 Single-Level Exposure - Discussion of Test Results

Detailed test data for Test 4 is contained in Appendix B. Test 4 was planned as a one-minute exposure. Unfortunately, immediately after ignition, a wind shift caused most of the fuel to move to the rear side of the test pan. Because of this, a ten-minute exposure of the container doors occurred. Although not part of the test plan, Test 4 provided an opportunity to evaluate the container doors and locking systems. Post-test examination revealed all doors to be still operable; however, extra effort was required to secure the locking rod cams in their keepers because the locking rods had bowed outward. No failure of hinges occurred and all door gaskets were charred but not totally destroyed, therefore, leakage of flame into the containers did not occur. The aluminum container's plymetal door outer panel of aluminum sheet had melted off and the plywood core was charred.

The interiors of the containers were examined after Test 4 to evaluate the effects of the test fire. No major damage to the container was noted. Since this test prevented the controlled escalation of fire exposure periods, and because the containers remained fairly intact, it was decided to fuel the test pan sufficiently to permit Test 5 to burn until complete destruction of the containers occurred. For this purpose, approximately 1-1/4 inches of JP-5 was floated on the water surface which resulted in an exposure of approximately fifteen minutes. Discussion of Test 5 is contained in Section 5.4.

5.3 Multi-Level Exposure - Theory

Test 6 was intended to simulate a full-scale container stack exposure with the wooden floors of the containers exposed to the pool fire. Nine containers were stacked in a three-by-three array shown in Figures 11 and 12. The water level in the test pan was lowered to approximately nine inches below the floorboards of the first row of containers. Sufficient fuel was then added to allow an exposure of approximately twenty-five minutes. The containers, their respective materials of construction, and time-temperature graphs for Test 6 are listed in Appendix B.

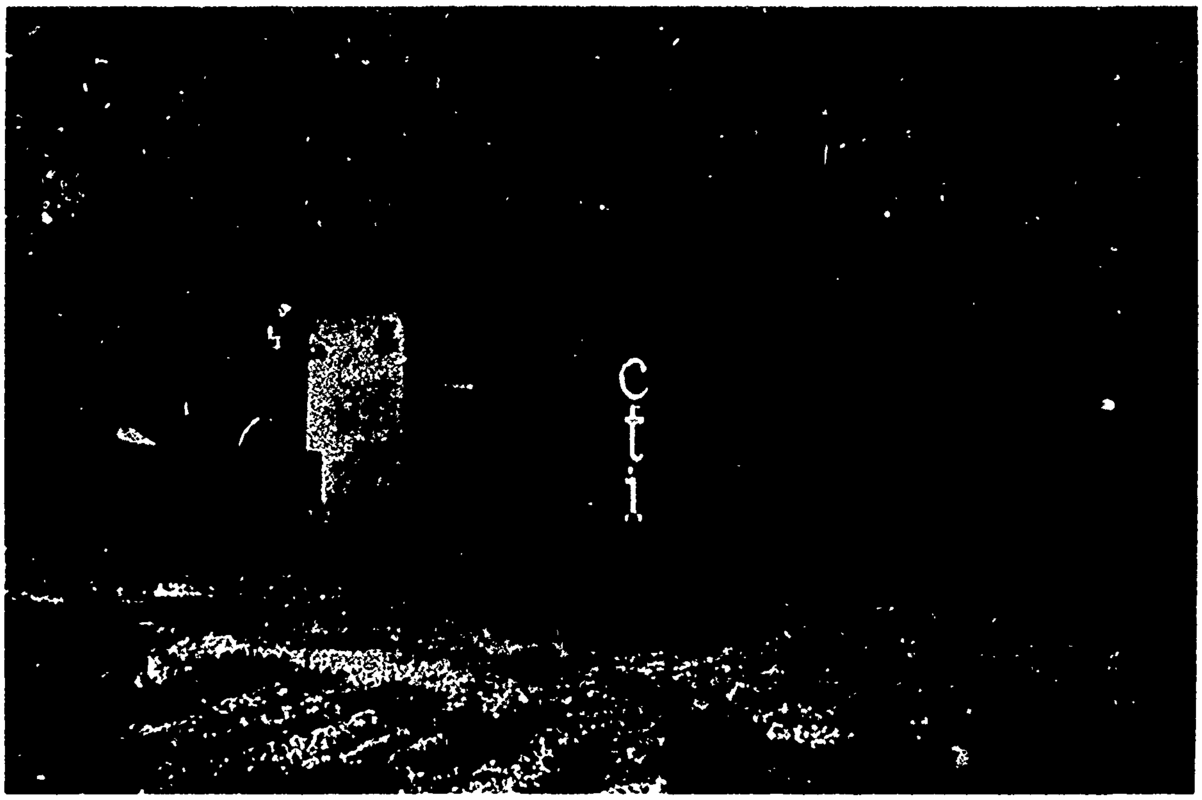


Figure 8 — Single Level Array of Containers

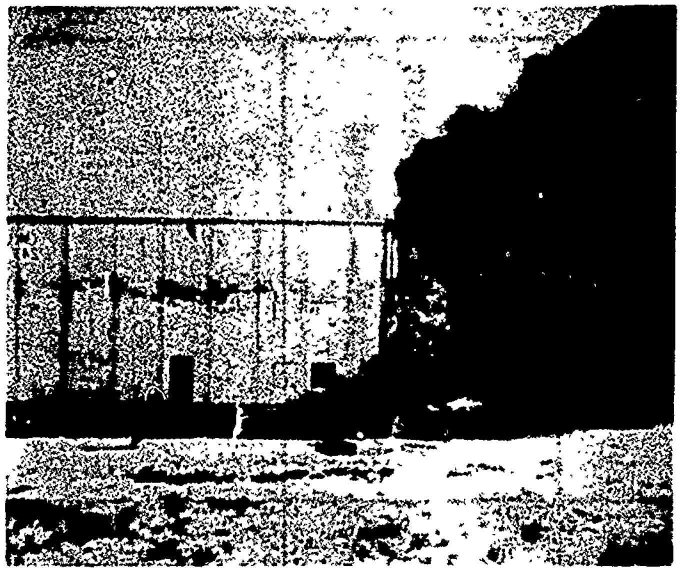


Figure 9 — Test Number Four

Figure 10 — Condition of Container Doors After Test Exposure

Container #3 Panels — Aluminum Frame — Steel	Container #6 Panels — Aluminum Frame — Steel	Container #9 Panels — Steel Frame — Steel
Container #2 Panels — Steel Frame — Steel	Container #5 Panels — FRP Frame — Steel	Container #8 Panels — Aluminum Frame — Steel
Container #1 Panels — FRP Frame — Aluminum	Container #4 Panels — Aluminum Frame — Steel	Container #7 Panels — FRP Frame — Aluminum

Figure 11 — Configuration of 3X3 Container Array

5.4 Discussion of Tests 4, 5, and 6

450°F (232°C) is the approximate temperature above which aluminum loses its structural integrity. It is also the approximate kindling point for many types of Class A materials. Therefore, it is at this temperature that the spread of fire in a container stack occurs; either by structural failure of aluminum container frame and panel components or by radiant or conducted heat energy to Class A materials. In Test 5, 450°F was reached in approximately four minutes in the interior of both the steel and aluminum containers, while the interior temperature of the FRP container did not reach this temperature for nine minutes. The frame and side panels of the aluminum container began to melt after four minutes of test exposure (Figure 13). The aluminum top frame rail of the FRP container did not melt during the test. It was noted, however, that the top rail had begun to deform where it was connected to the steel end frame (Figure 14). It is felt that the thermal insulating properties of the FRP side panels helped to limit the transfer of heat to these components.

Table 3 is a comparison of the relative heat absorption rates of the containers tested in the multi-level configuration. As can be noted from this table and from the detailed time-temperature data in Appendix B, the temperature rise to 450°F in all containers occurred at approximately the same rate. In the top row of containers, with the exception of Container 9, this temperature rise was delayed for approximately five minutes. Container 9 was directly exposed to the effects of the pool fire when the collapse of Containers 7 and 8 occurred at approximately ten minutes.

In Tests 4 and 5, the containers were free-standing on the hatch cover. In Test 6, the containers were stacked and lashed which imposed a load upon the bottom row of containers not experienced in previous tests. Additionally, the undersides of the container floorboards were exposed to the fire in Test 6. These two factors could account for the differing test results between Tests 5 and 6. The bottom level of containers used in the one-level array for Test 5 reached this temperature in approximately four minutes. The bottom row of containers in the three-level configuration used for Test 6 did not reach 450°F for nearly ten minutes. However, when this temperature was reached, the collapse of Containers 1 and 7, which had aluminum frames, occurred. The remainder of the containers had steel frames except Container 5 which had an aluminum front end-frame. Throughout Test 6, the middle column of containers remained in place with Containers 3 and 9 also being held in place by the bridge fittings (Figure 15). It was the eventual failure of the aluminum front end-frame of Container 5 that caused the total collapse of the container stack.

TABLE 3

EXTERIOR FIRE TESTS

MULTI-LEVEL ARRAY

- TEST 6 -

Container Number	Row	Column	Time To Reach 100°C	Time to Reach 232°C (450°F)	Time To Reach 500°C
1	1	1	7 min.	9 min.	12 min.
2	2	1	9 min.	10 min.	14 min.
3	3	1	10 min.	15 min.	17 min.
4	1	2	9 min.	11 min.	14 min.
5	2	2	10 min.	15 min.	16 min.
6	3	2	12 min.	14 min.	15 min.
7	1	3	10 min.	11 min.	13 min.
8	2	3	8 min.	9 min.	10 min.
9	3	3	8 min.	9 min.	10 min.

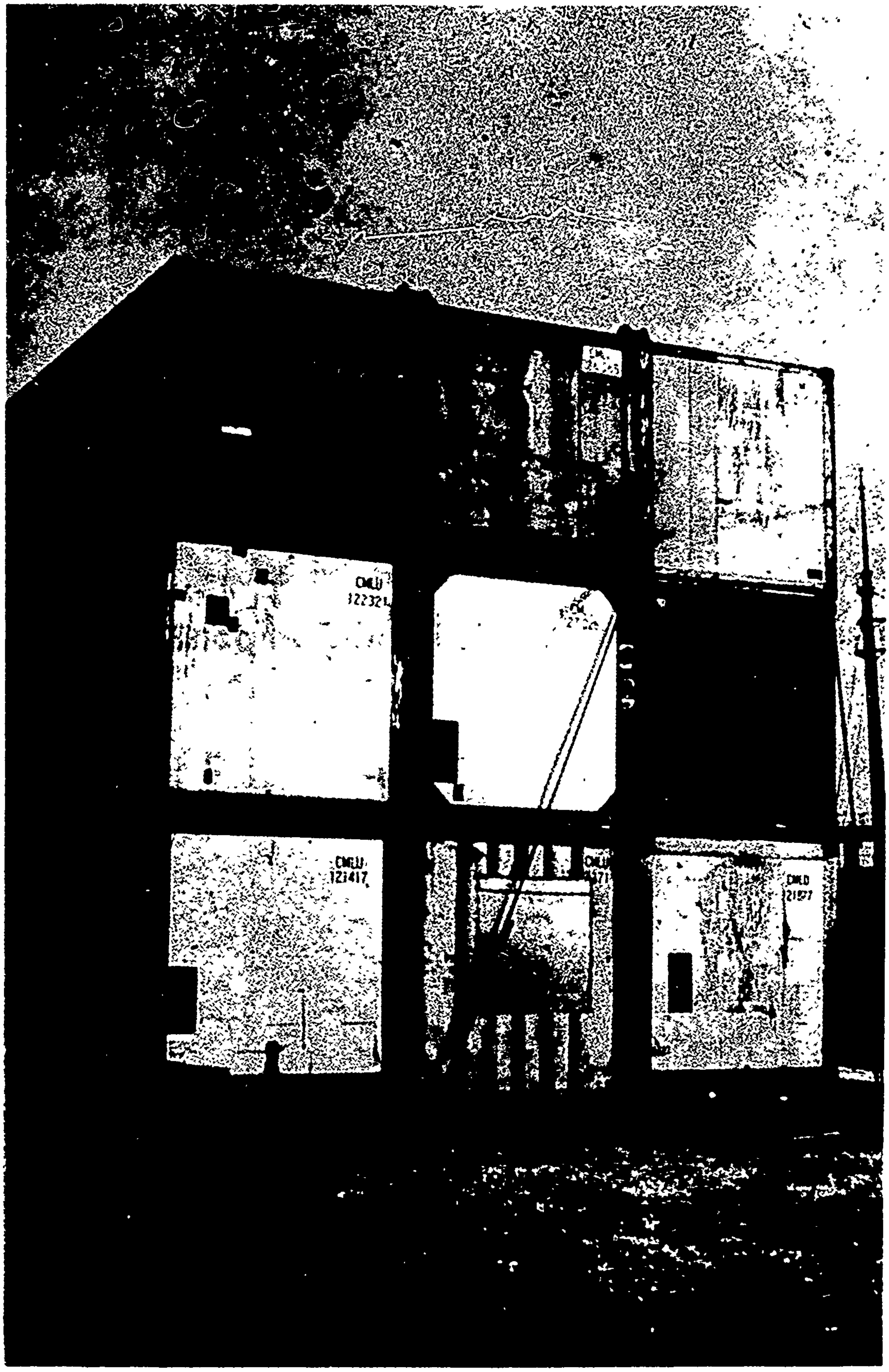


Figure 12 — Three-by-Three Array Test Six

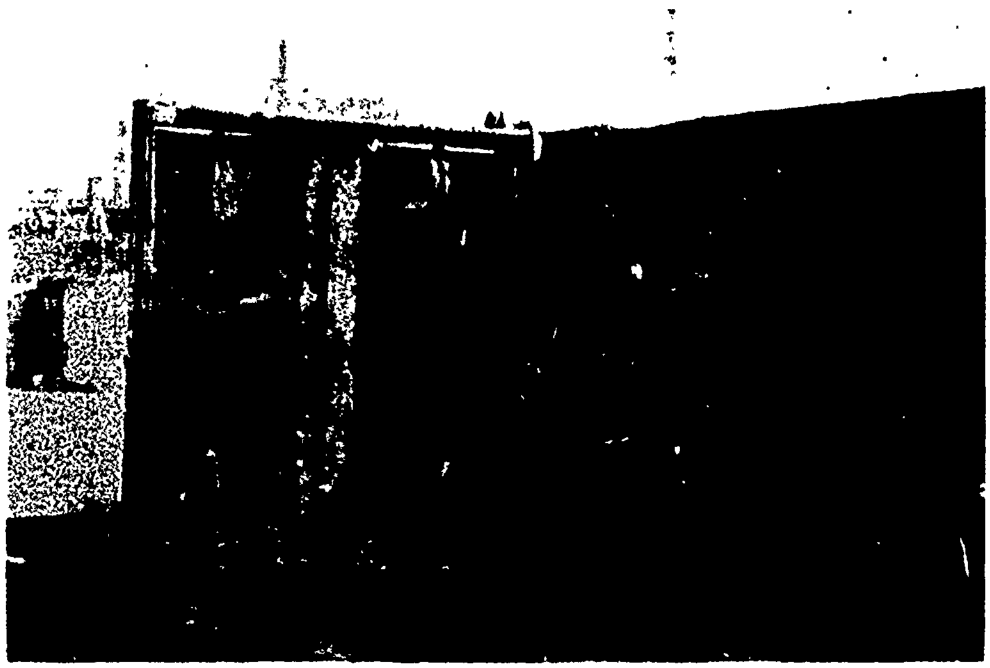


Figure 13 — Melted Aluminum Components

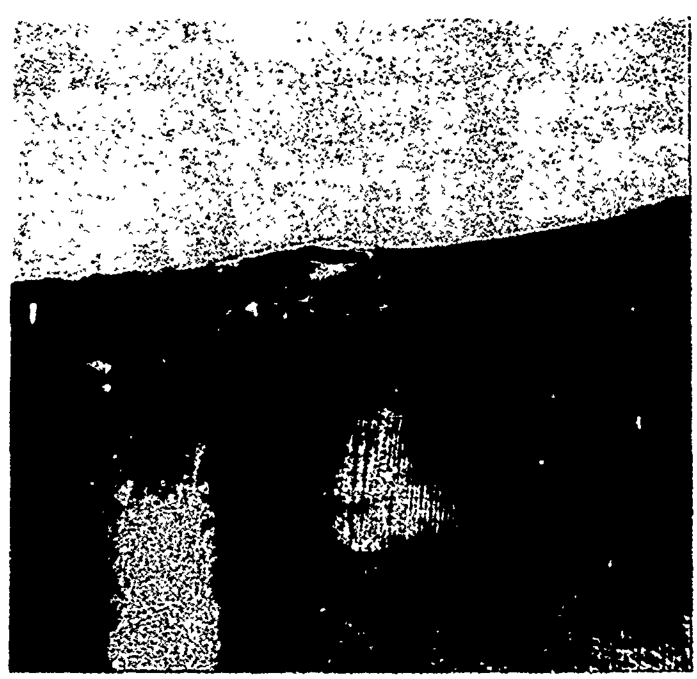


Figure 14 — Buckled Aluminum Top Rail

Figure 15 — Containers Held in Place by Bridge Fittings

Figure 16 — Collapse of Container # 5

6.0 CONCLUSIONS

A. Steel containers do not act as a barrier to prevent the spread of flame through a container stack. The failure of steel container panels did not occur in any of the tests. Additionally, steel containers are non-combustible and do not add to the fuel load of the cargo.

However, as a result of these tests, it can be shown that the transfer of a fixed amount of heat to the interior of a container from an external heat source will occur in approximately equal time period for both steel and plywood-lined aluminum containers. A JP-5 pool fire source of approximately 30,000 BTU/FT^2-hour as used for these tests could cause the potential ignition or charring of Class A materials inside a sealed steel or aluminum container in approximately five minutes. If a steel container were placed in a container stack to act as a barrier, it would merely delay the transfer of heat to adjacent containers for several minutes.

B. Extruded aluminum alloy frames do not provide an equivalent amount of structural integrity as high tensile strength steel frames during fire exposure. In Test 6, the eventual collapse of the container stack was caused by the failure of aluminum frame components (Figure 16). Containers 1 and 7, which failed initially, utilized total aluminum frame hardware. The spread of flame through a container stack is caused by the transfer of radiant heat energy to intact containers. Aluminum frame components or side panels will melt under fire exposure, causing the spread of flame to the container contents and, consequently, to adjacent containers.

C. An interior fire in a sealed, non-damaged container will become oxygen regulated before any of the container panels are breached. All interior test fires were self-extinguished from oxygen depletion. Similar results were noted in a test series conducted by the Netherlands Ship Research Centre (Section 4.3).

D. The wooden floorboards used in container construction do not add to the rapid spread of fire through a container stack. As discussed above, an external fire will cause the transfer of a sufficient amount of heat through all three types of container panels to ignite Class A materials within approximately five minutes and, within a short time thereafter, melt aluminum frame components. Laboratory tests[4] of double thicknesses of nominal one-inch tongue and groove laminated hardwood flooring show that twelve to eighteen minutes is required to reach 250°F (132°C) on the unexposed side of the floor when exposed to the ASTM E-119 test furnace. It follows that the transfer of heat through 1-1/8" or 1-1/4" container floorboards will require from six to nine minutes to reach a point where the unexposed surface temperature will approach the higher temperature of 450°F. This is equal to or greater than the time required for this amount of heat to be transferred through the container roof or side panels to the aluminum frame components.

E. The stacking and lashing fittings currently used provide an adequate amount of structural stability under fire conditions. In Test 6, the bridge fittings maintained the top row of containers in position even though the bottom end containers had collapsed (Figure 15).

7.0 SUMMARY

The findings of this study indicate several important aspects of container shipping. An incident resulting in the ignition of cargo within a sealed, non-damaged container would not endanger adjacent containers. However, a typical container stack exposed to an exterior fire source for more than approximately five minutes can structurally fail, melt, or transfer radiant heat to cause the spread of flame to adjacent container stacks. External fire exposure will produce nearly identical results, after a certain amount of time, in all three types of containers. For this reason it is felt that, unless restrictive economical measures are taken, no changes in basic container construction or materials can provide a substantial gain in fire protection capability. The typical containers in use today do not act to intensify a deck cargo fire nor do they impede the spread of flame for more than several minutes. An exterior fire in a container stow can spread unless controlled by the installed fire protection system. It is essential that fixed fire-fighting systems be capable of rapid activation and application. It is also necessary to insure adequate capacity for the installed fire-fighting system.

If not initially controlled, an on-deck container fire could progress until it exceeds the design application rate of the installed fire-fighting system, and at such time, the entire on-deck container load will be jeopardized.

APPENDIX A

INTERIOR FIRE TEST DATA

REFERENCES

1. National Fire Protection Association, "Fire Protection Handbook," 13th edition, 1969, Boston, MA, page 5-9.

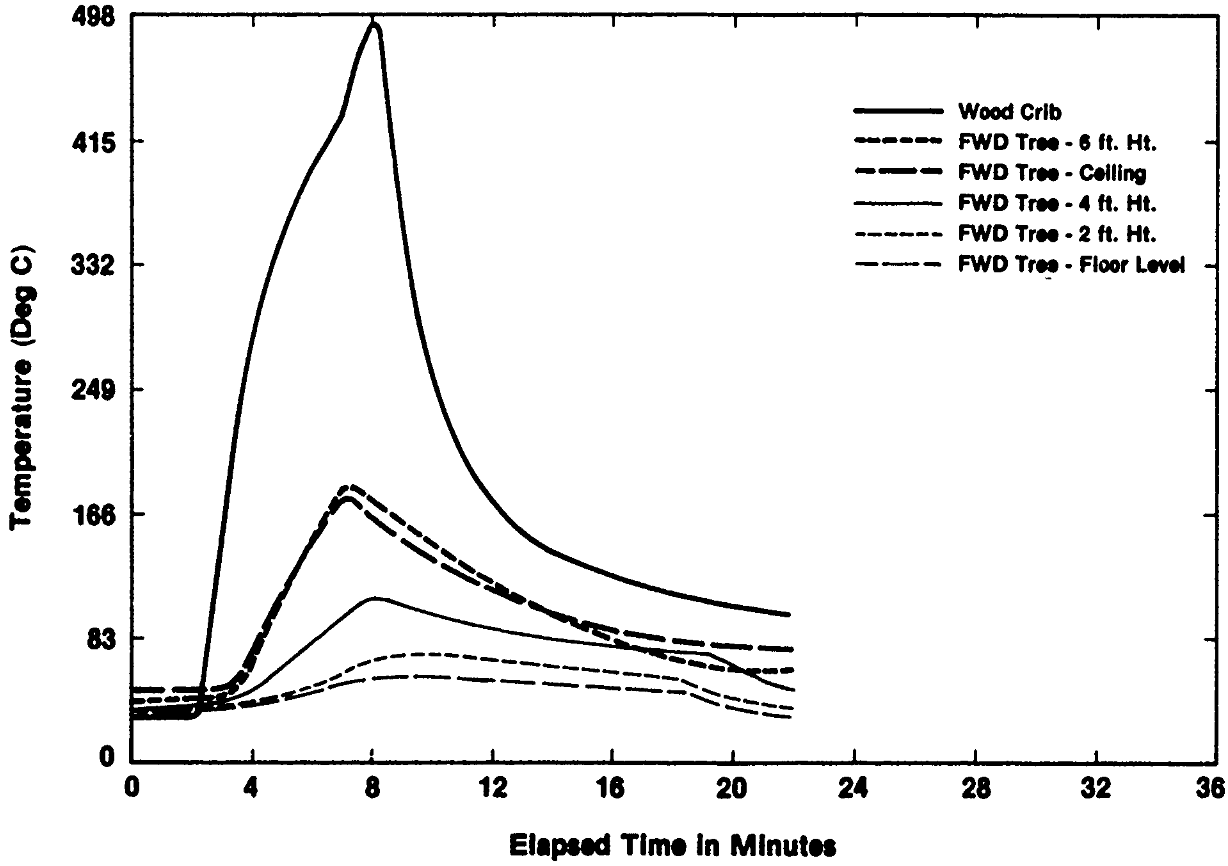
2. Souer, H. J., "Marine Transportation of Containerized Cargo," Part III, Netherlands Ship Research Centre TNO, Report Number 202M, November 1974.

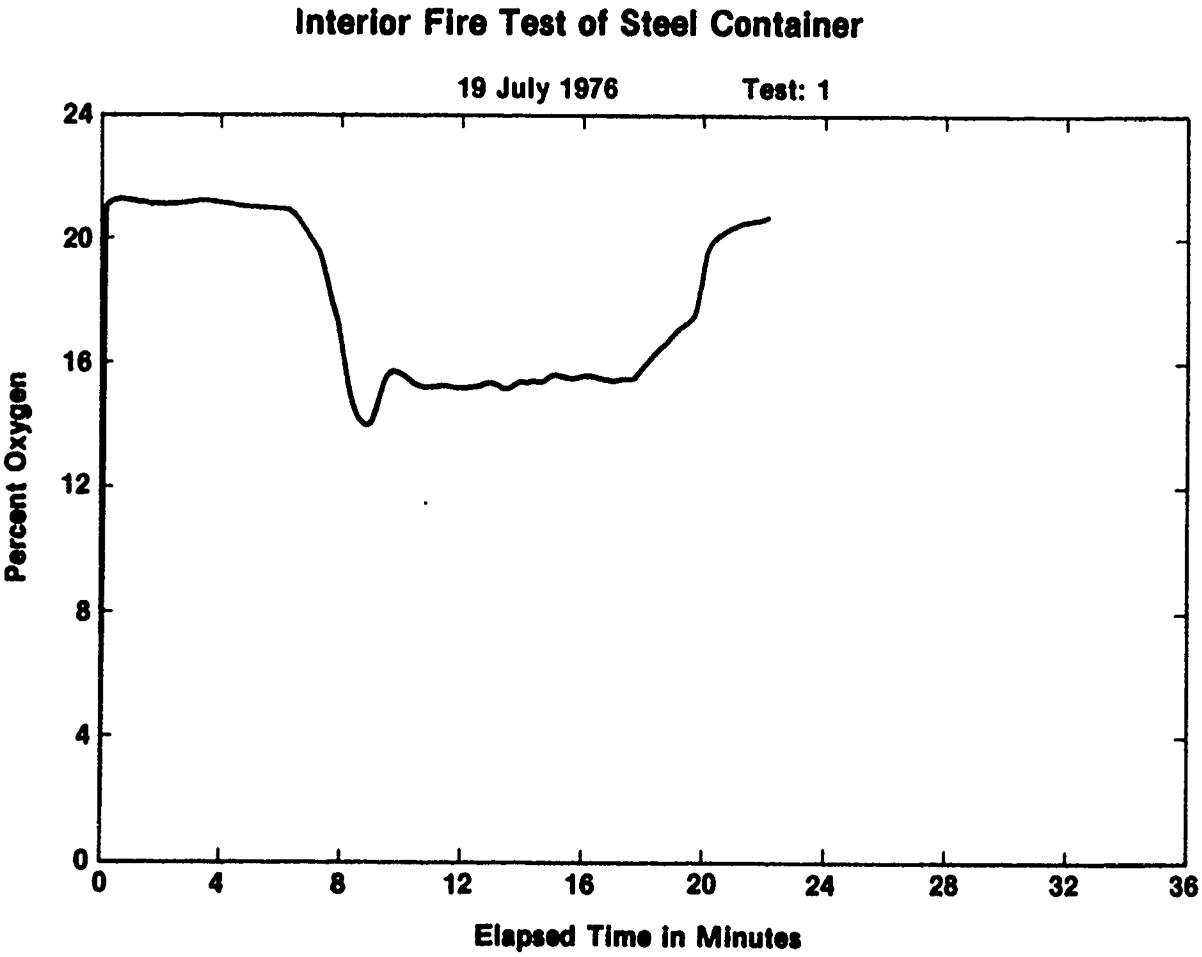
3. Souer, H. J., "Marine Transportation of Containerized Cargo," Part V, Netherlands Ship Research Centre TNO, Report Number 202M, November 1974.

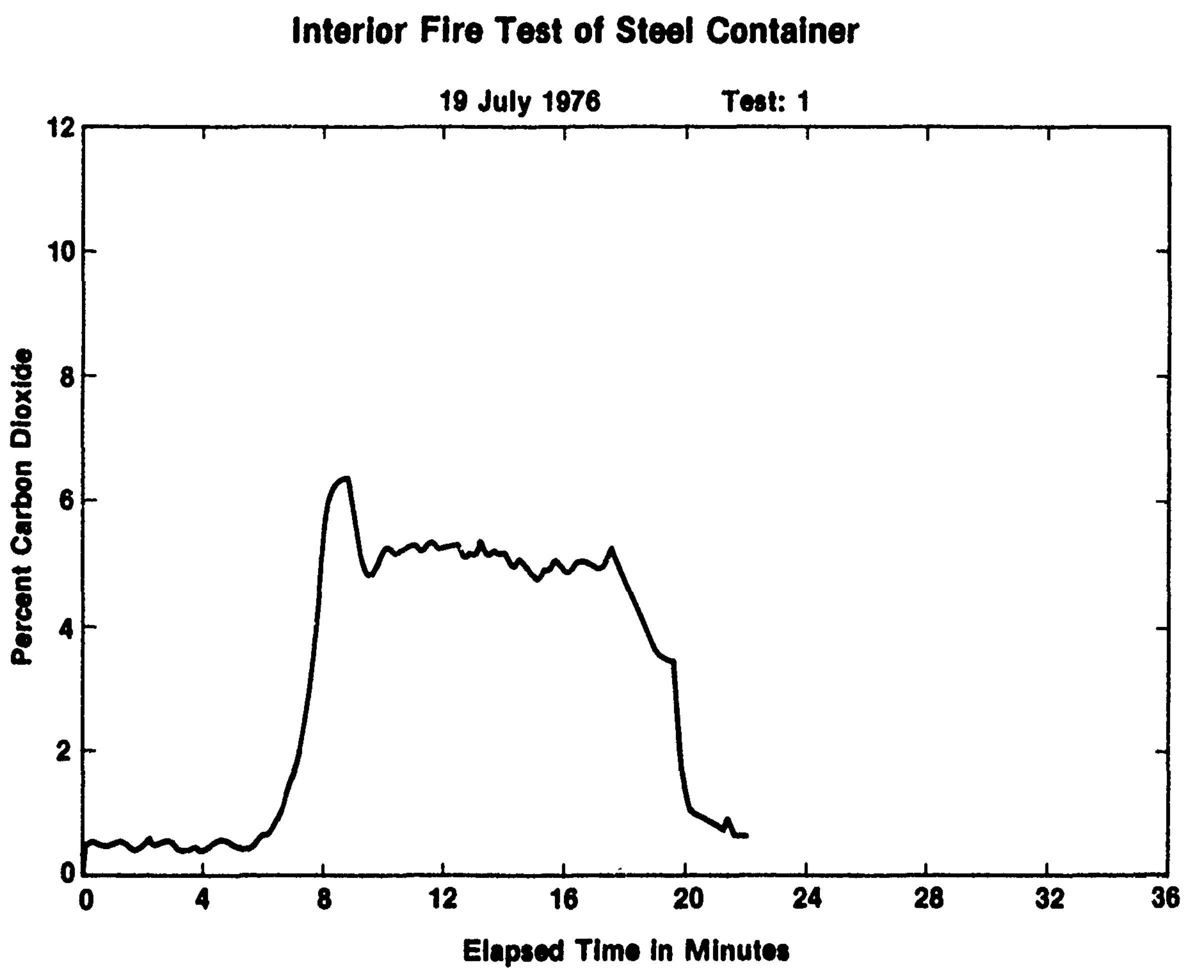
4. Underwriters' Laboratories, Inc., "Fire Resistance Directory," 1977, Northbrook, IL, Sections L and M.

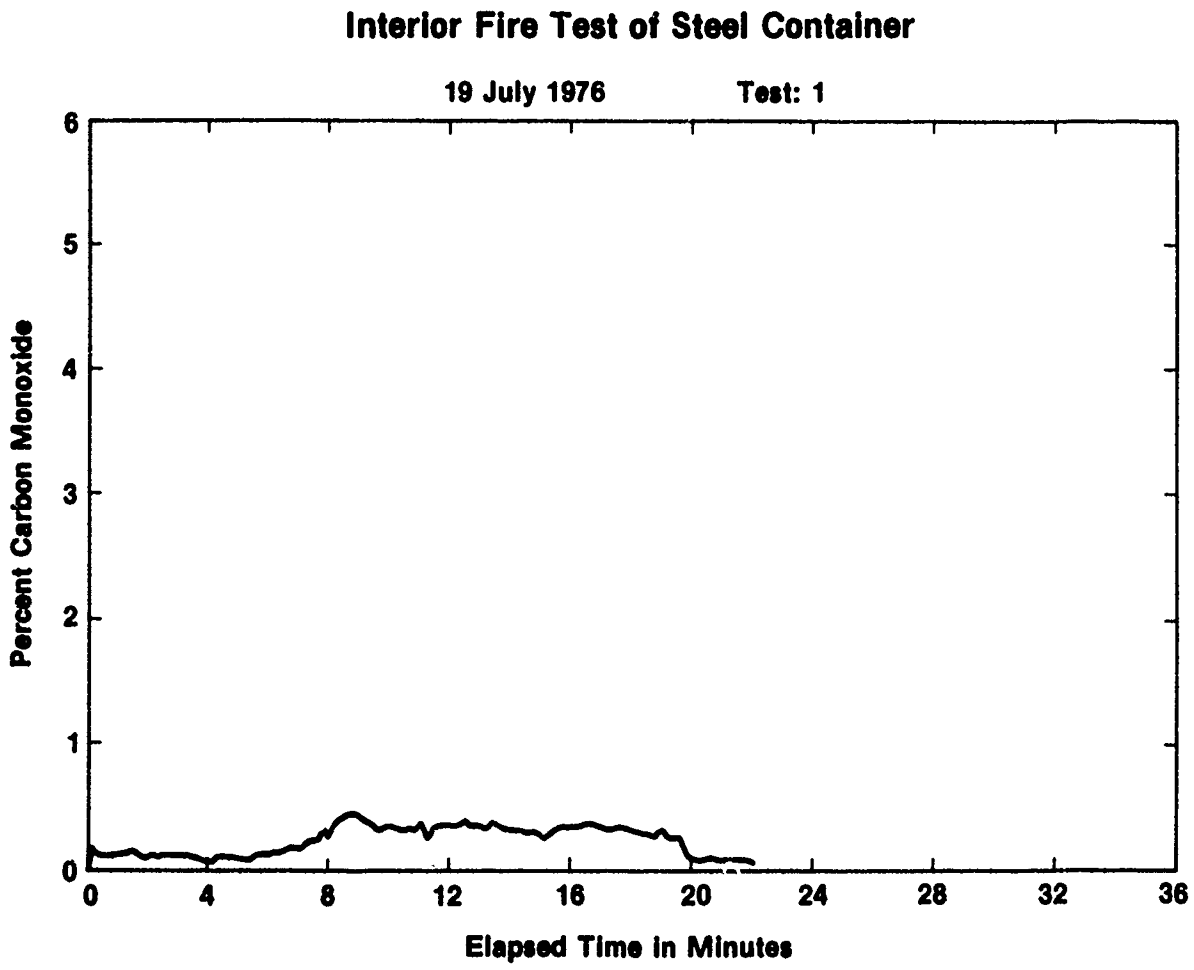
Interior Fire Test of Steel Container

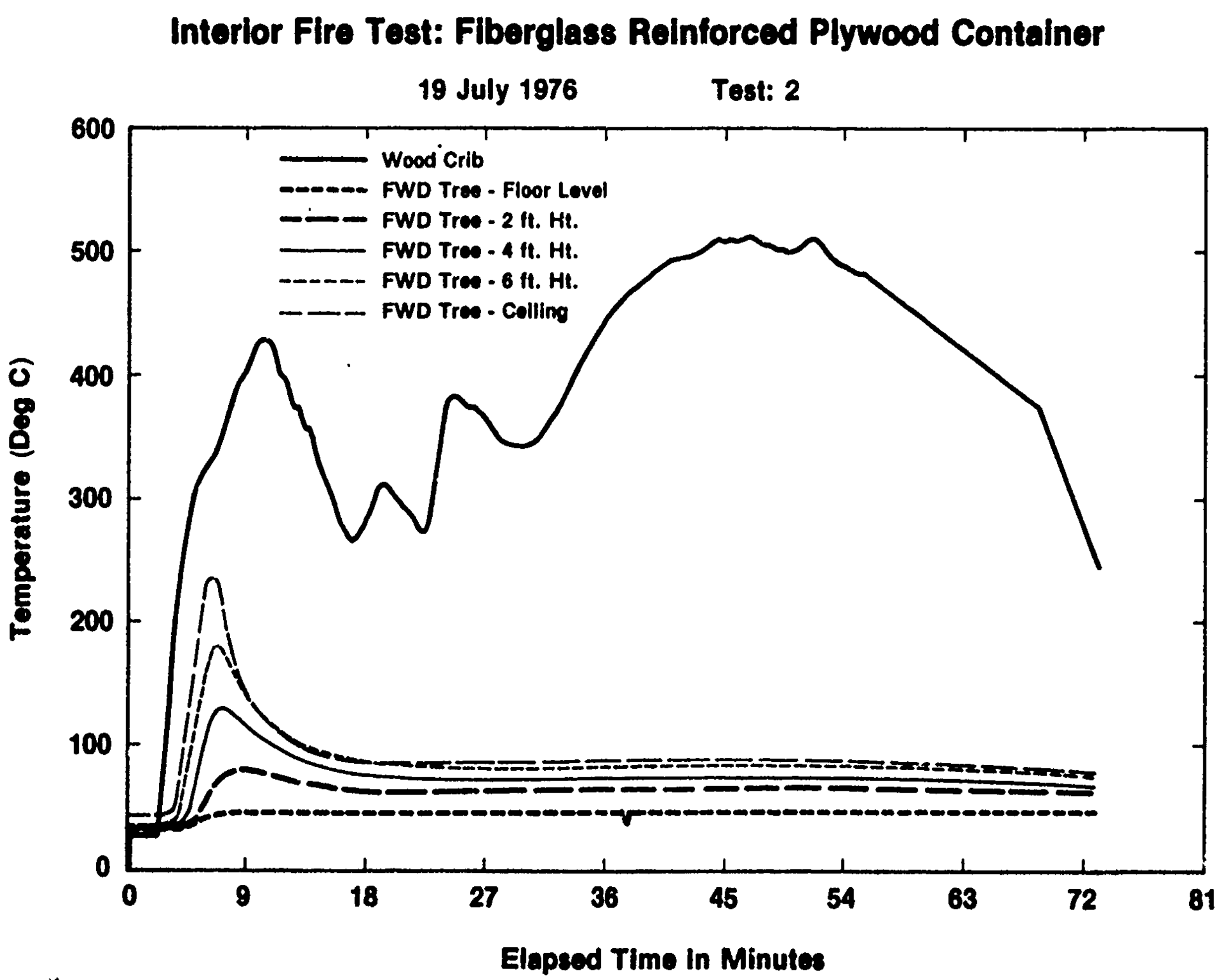
19 July 1976 Test: 1



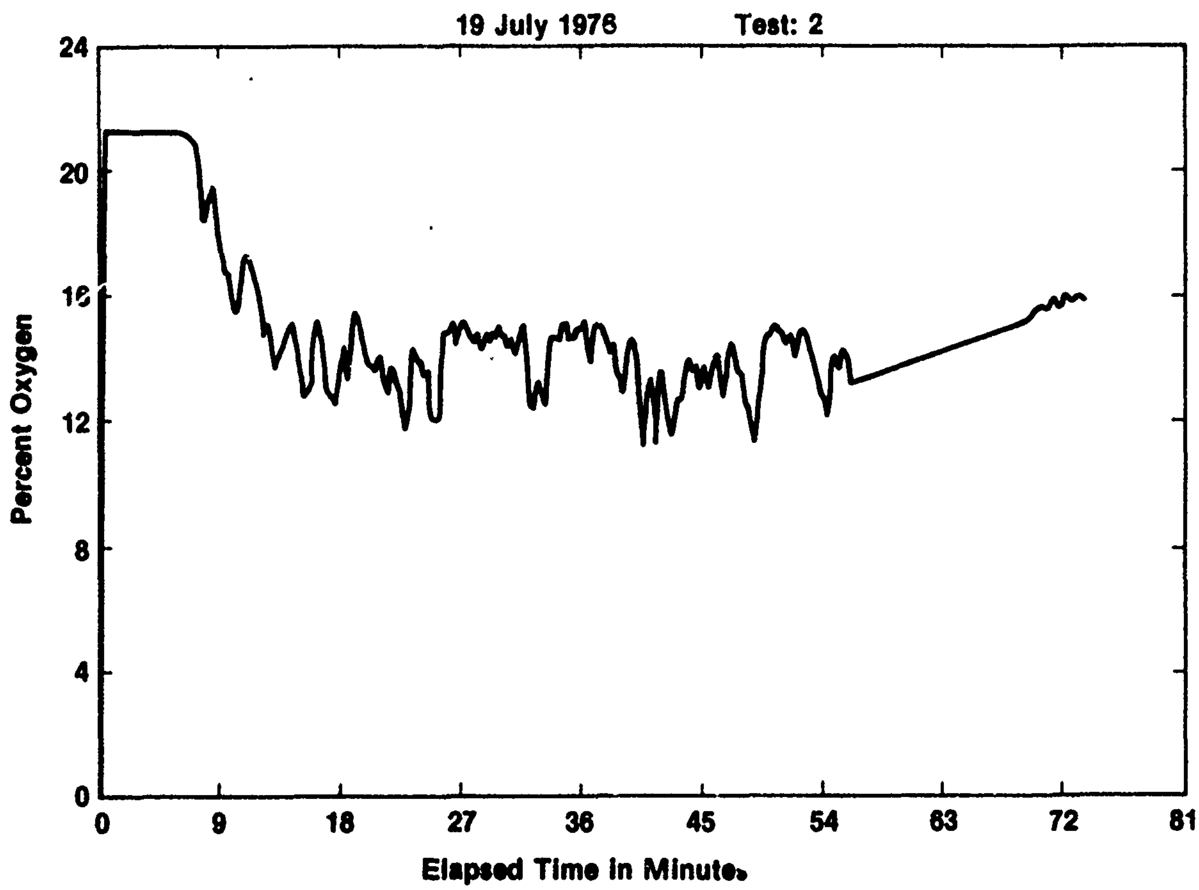

Interior Fire Test of Steel Container
19 July 1976
Test: 1
Percent Oxygen
Elapsed Time in Minutes
0
4
8
12
16
20
24
28
32
36


Interior Fire Test of Steel Container
19 July 1976
Test: 1
Percent Carbon Dioxide
0
2
4
6
8
10
12
0
4
8
12
16
20
24
28
32
36
Elapsed Time in Minutes


Interior Fire Test of Steel Container
19 July 1976
Test: 1
Percent Carbon Monoxide
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
Elapsed Time in Minutes

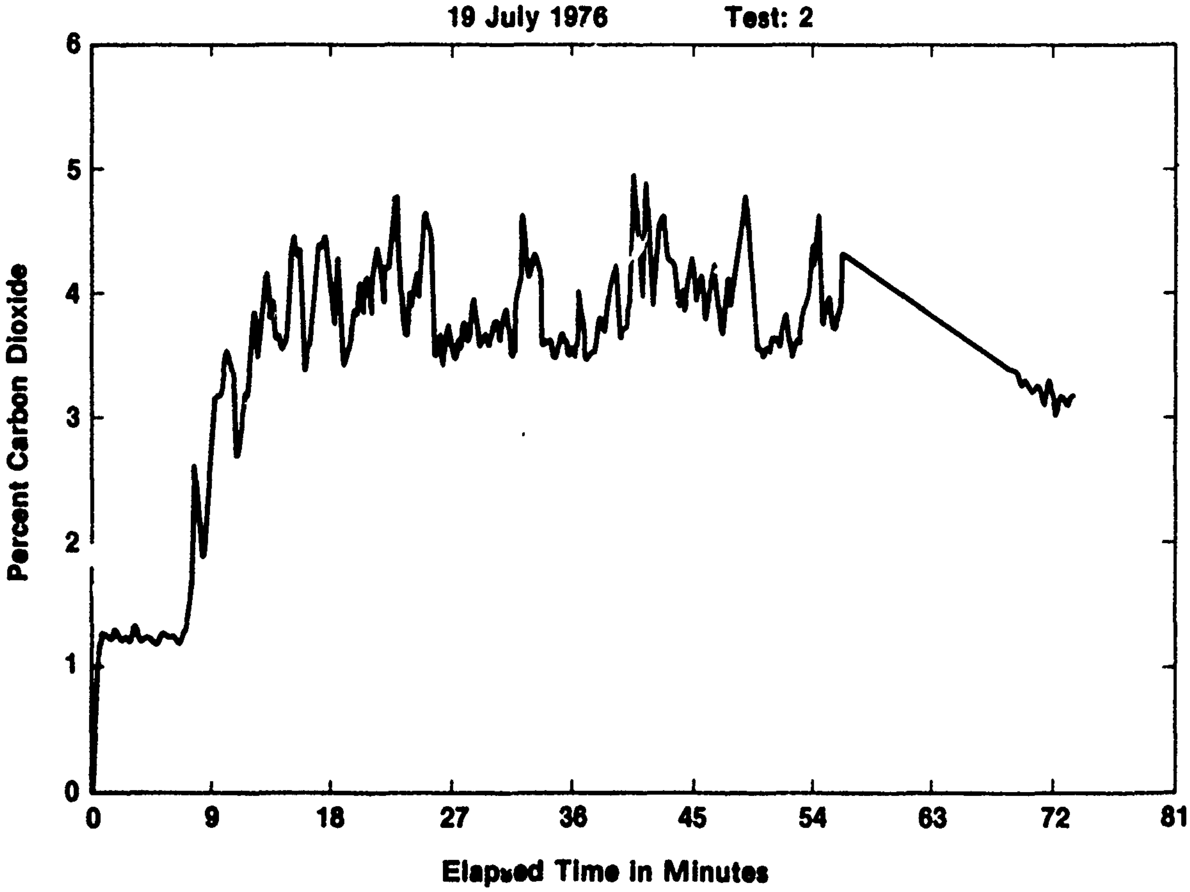

Interior Fire Test: Fiberglass Reinforced Plywood Container
19 July 1976
Test: 2
Wood Crib
FWD Tree - Floor Level
FWD Tree - 2 ft. Ht.
FWD Tree - 4 ft. Ht.
FWD Tree - 6 ft. Ht.
FWD Tree - Ceiling
Temperature (Deg C)
600
500
400
300
200
100
0
0
9
18
27
36
45
54
63
72
81
Elapsed Time in Minutes

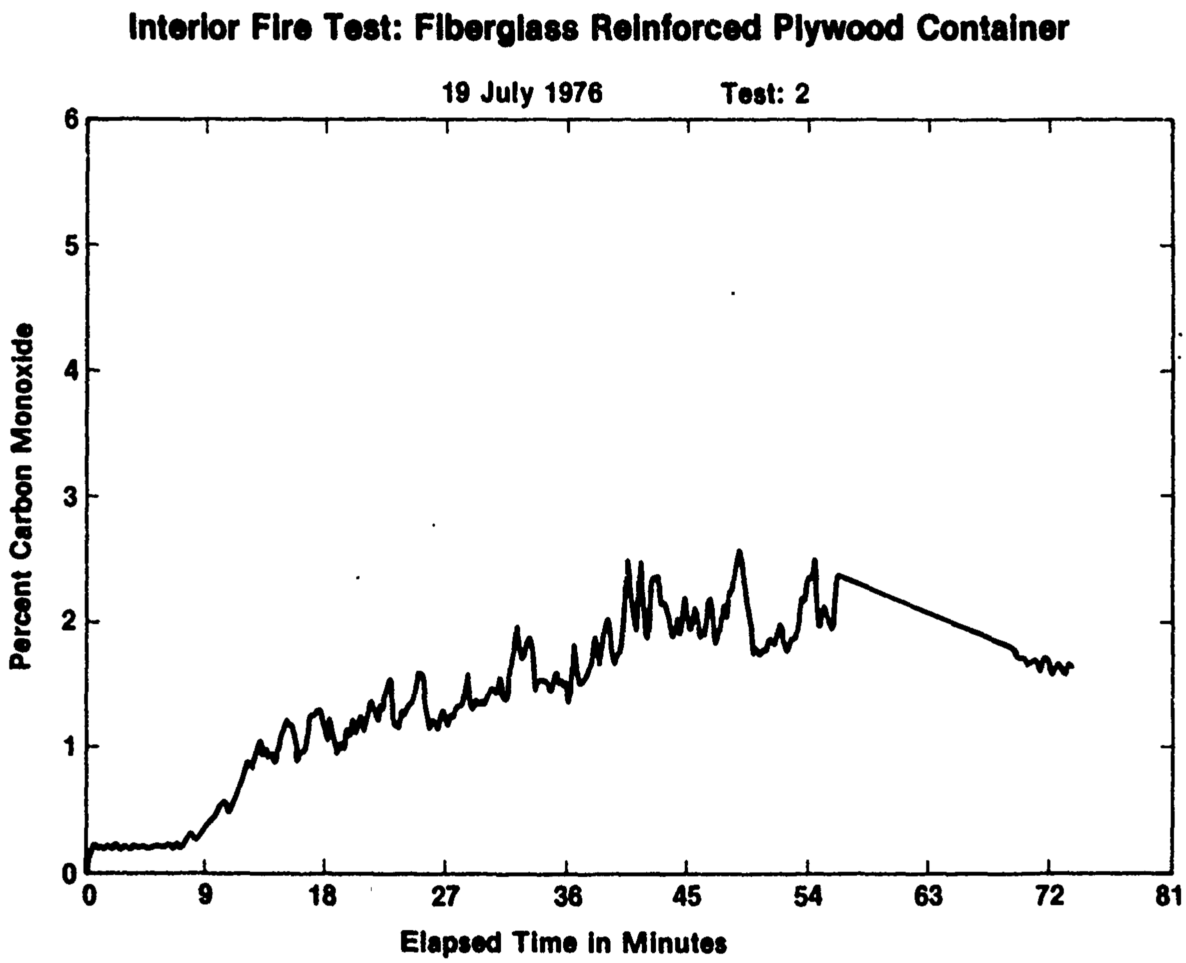
Interior Fire Test: Fiberglass Reinforced Plywood Container



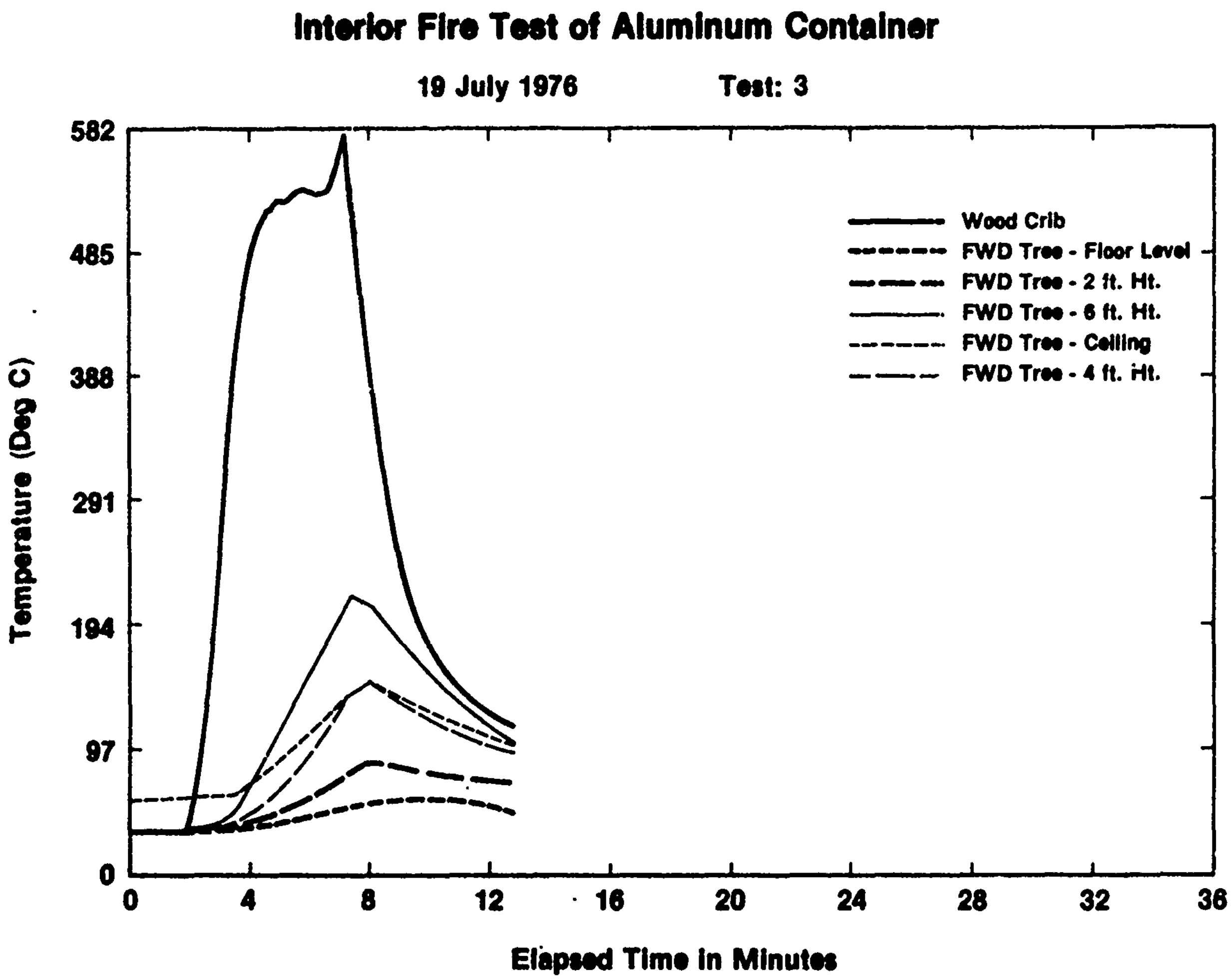
Interior Fire Test: Fiberglass Reinforced Plywood Container

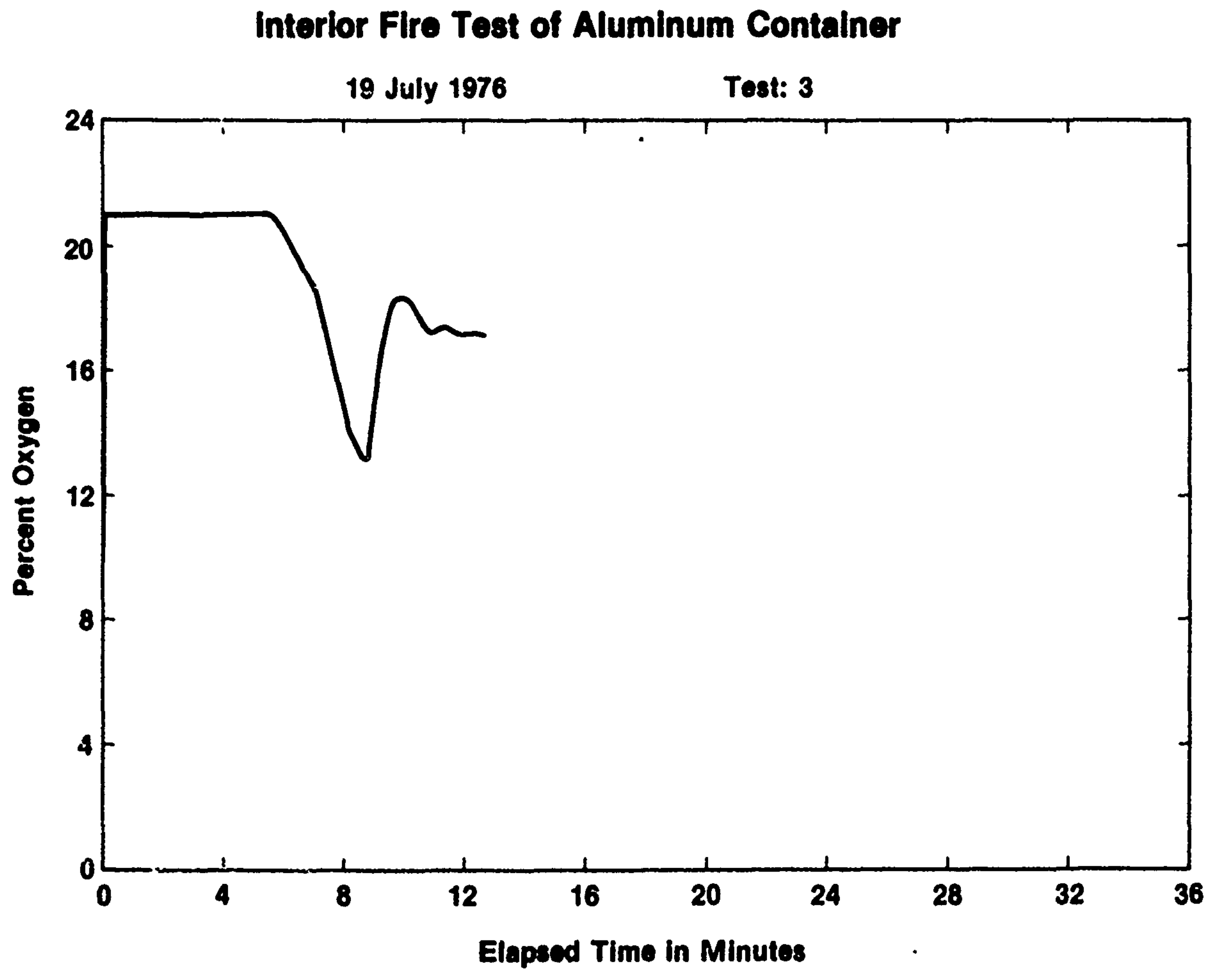
19 July 1976 Test: 2



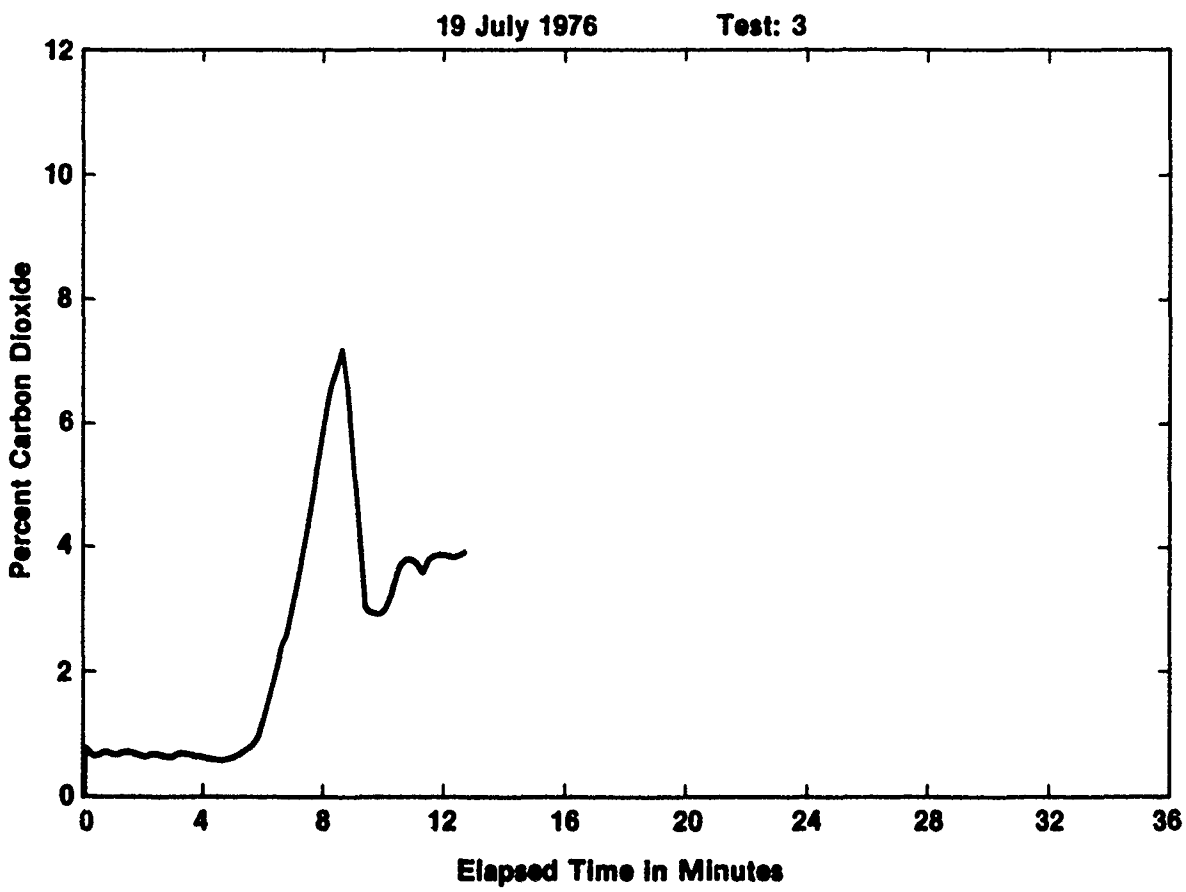


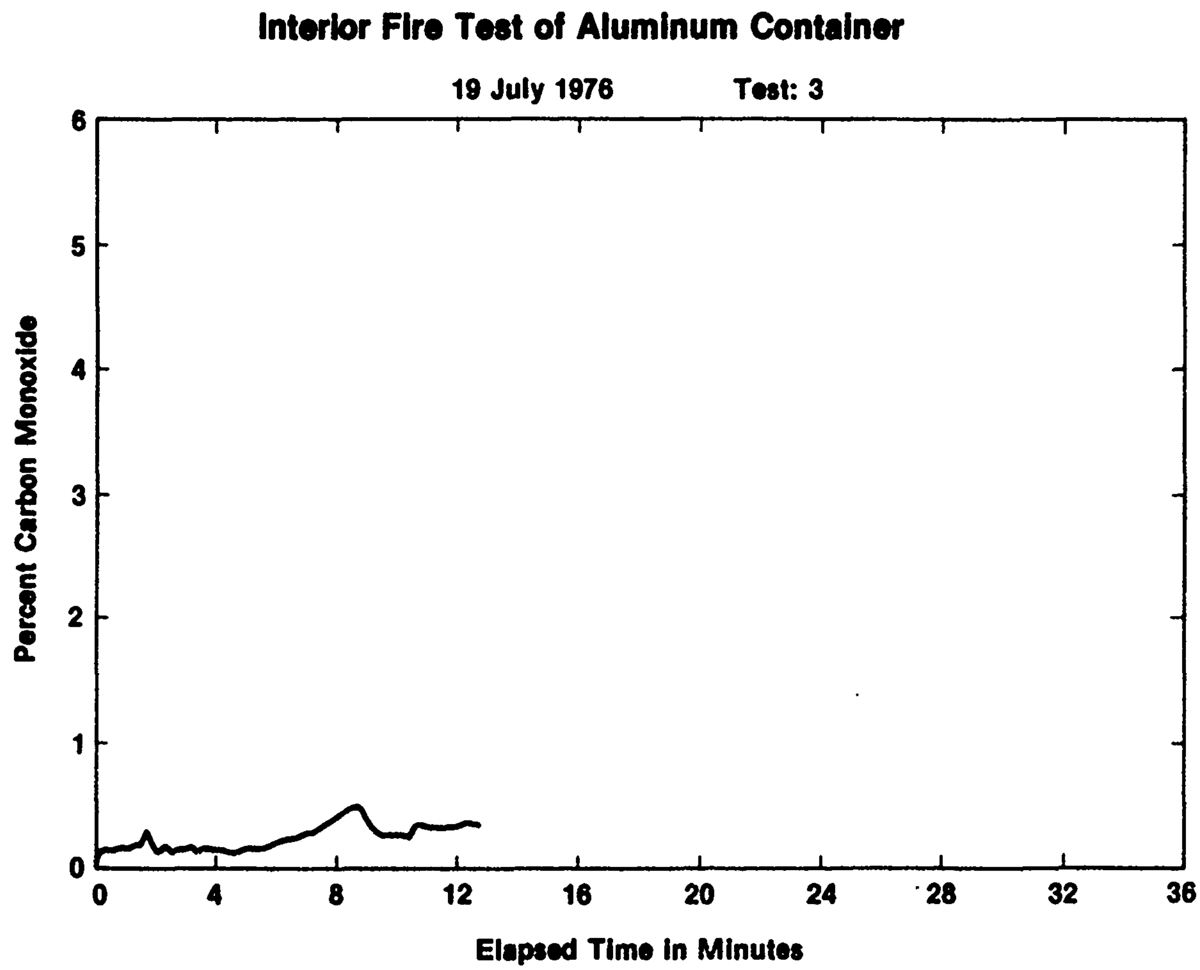
Interior Fire Test: Fiberglass Reinforced Plywood Container
19 July 1976
Test: 2
Percent Carbon Monoxide
0
1
2
3
4
5
6
0
9
18
27
36
45
54
63
72
81
Elapsed Time in Minutes


Interior Fire Test of Aluminum Container
19 July 1976
Test: 3
582
485
388
291
194
97
0
Temperature (Deg C)
0
4
8
12
16
20
24
28
32
36
Elapsed Time in Minutes
Wood Crib
FWD Tree - Floor Level
FWD Tree - 2 ft. Ht.
FWD Tree - 6 ft. Ht.
FWD Tree - Ceiling
FWD Tree - 4 ft. Ht.


Interior Fire Test of Aluminum Container
19 July 1976
Test: 3
Percent Oxygen
Elapsed Time in Minutes
0
4
8
12
16
20
24
28
32
36

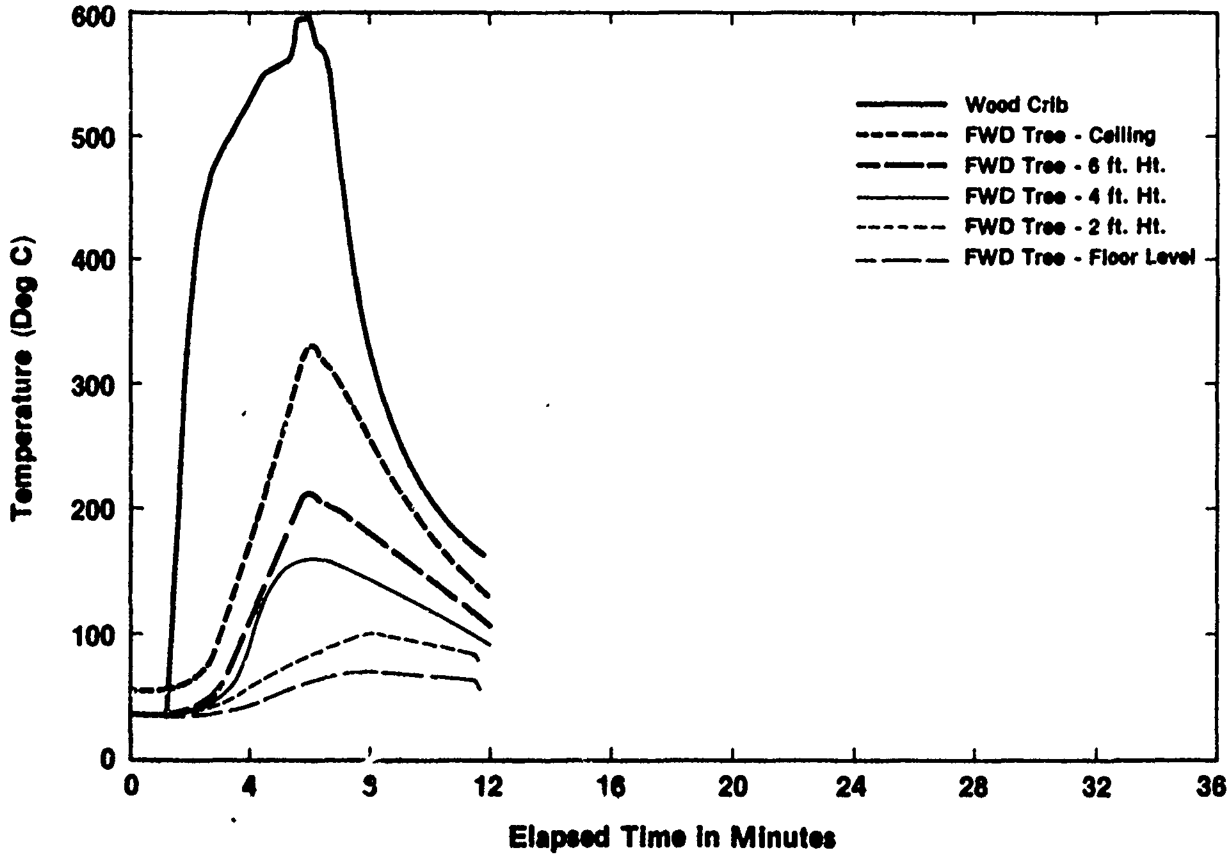
Interior Fire Test of Aluminum Container



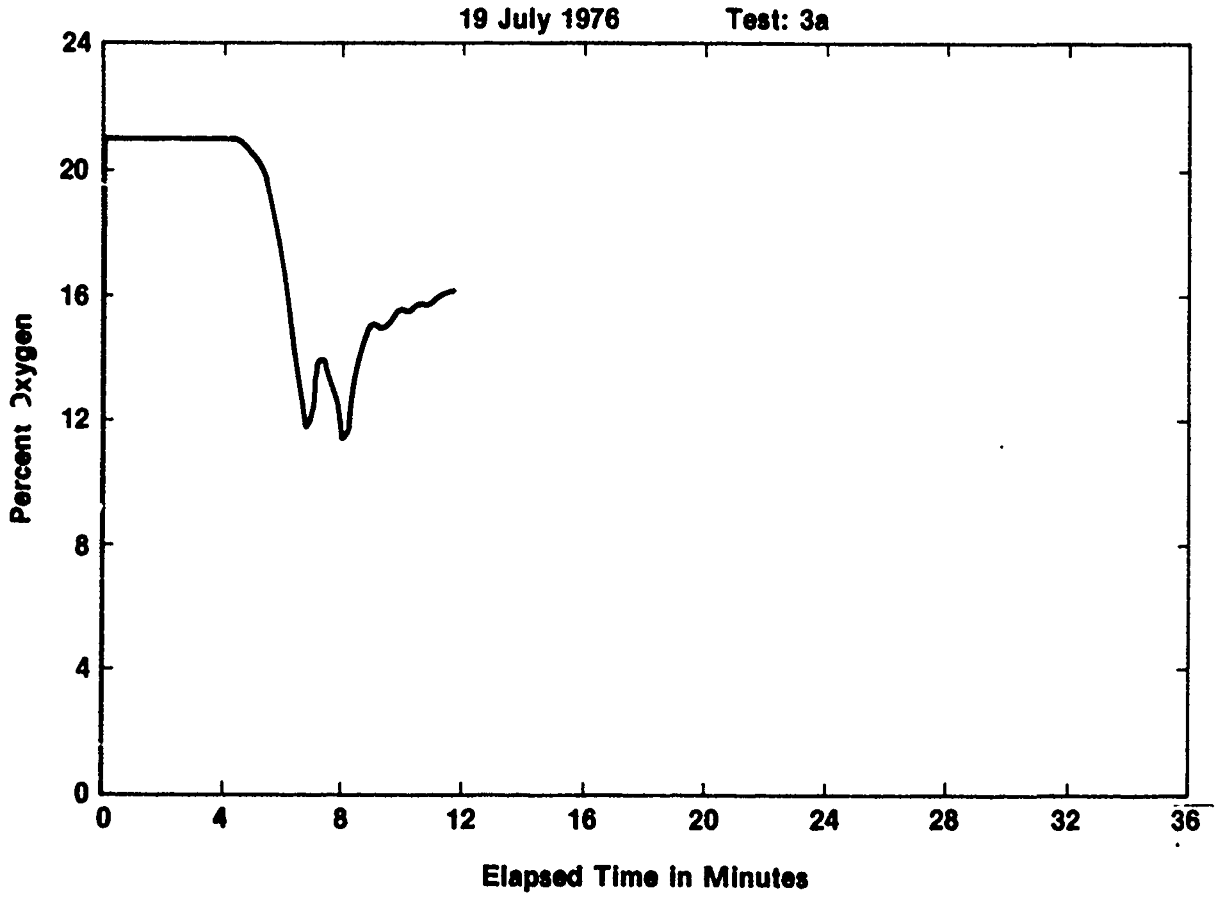

Interior Fire Test of Aluminum Container
19 July 1976
Test: 3
Percent Carbon Monoxide
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
Elapsed Time in Minutes

Interior Fire Test of Aluminum Container

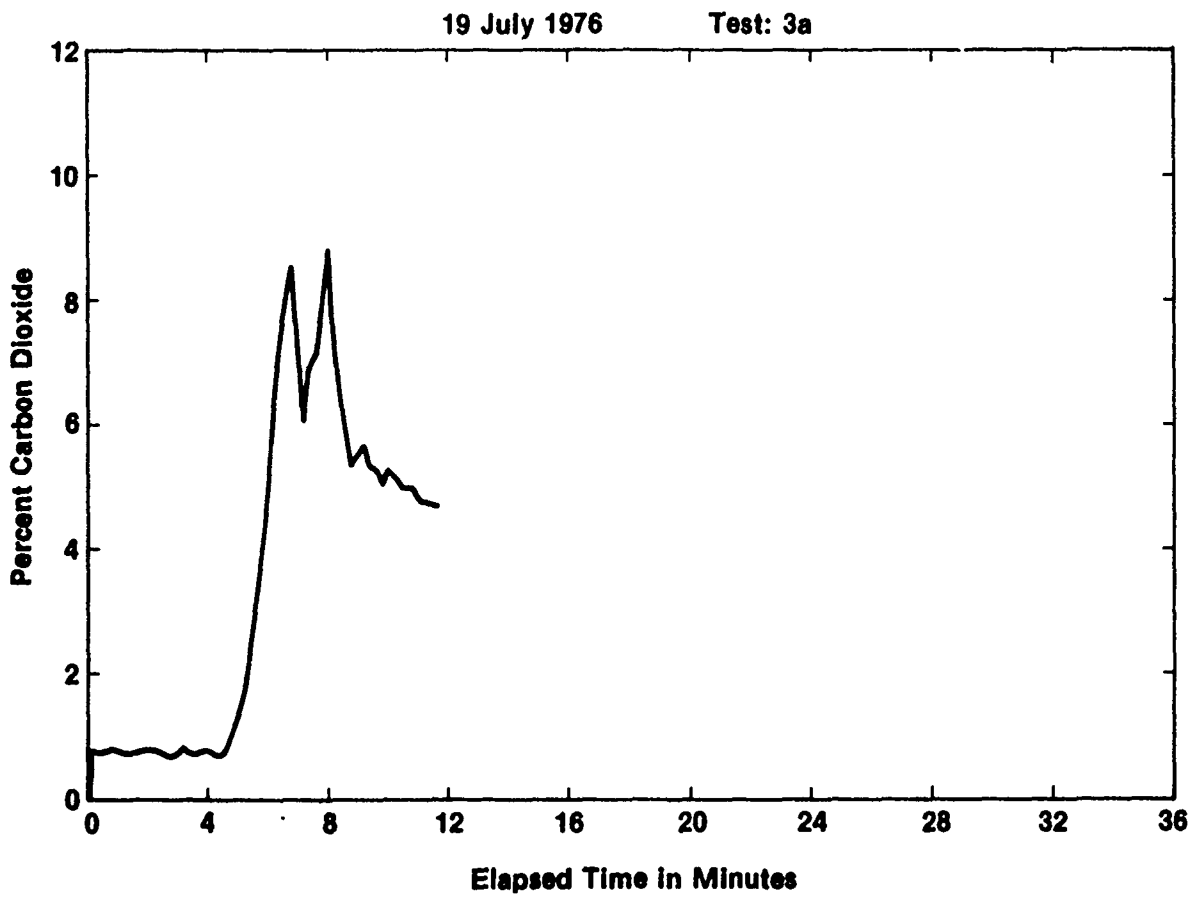
19 July 1976 Test: 3a

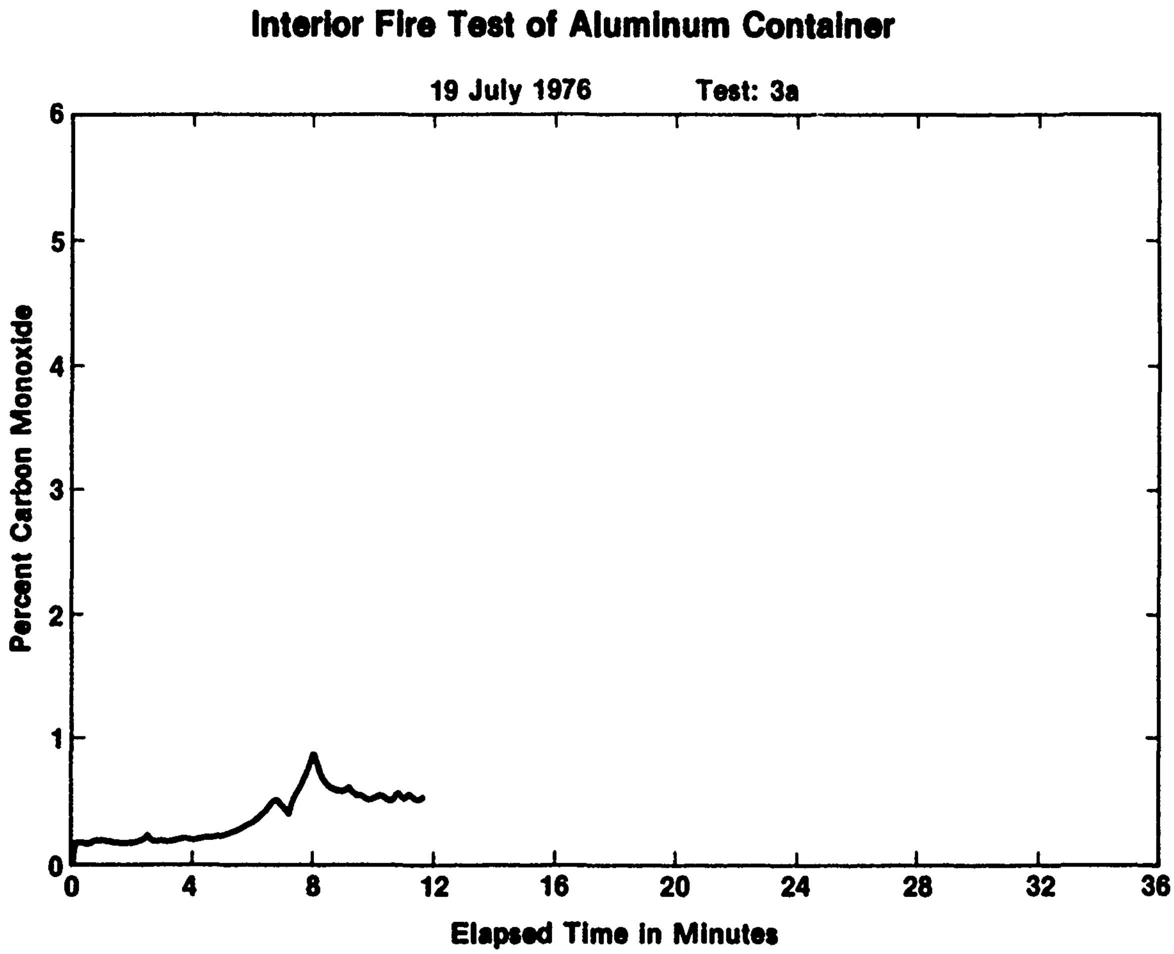


Interior Fire Test of Aluminum Container



Interior Fire Test of Aluminum Container



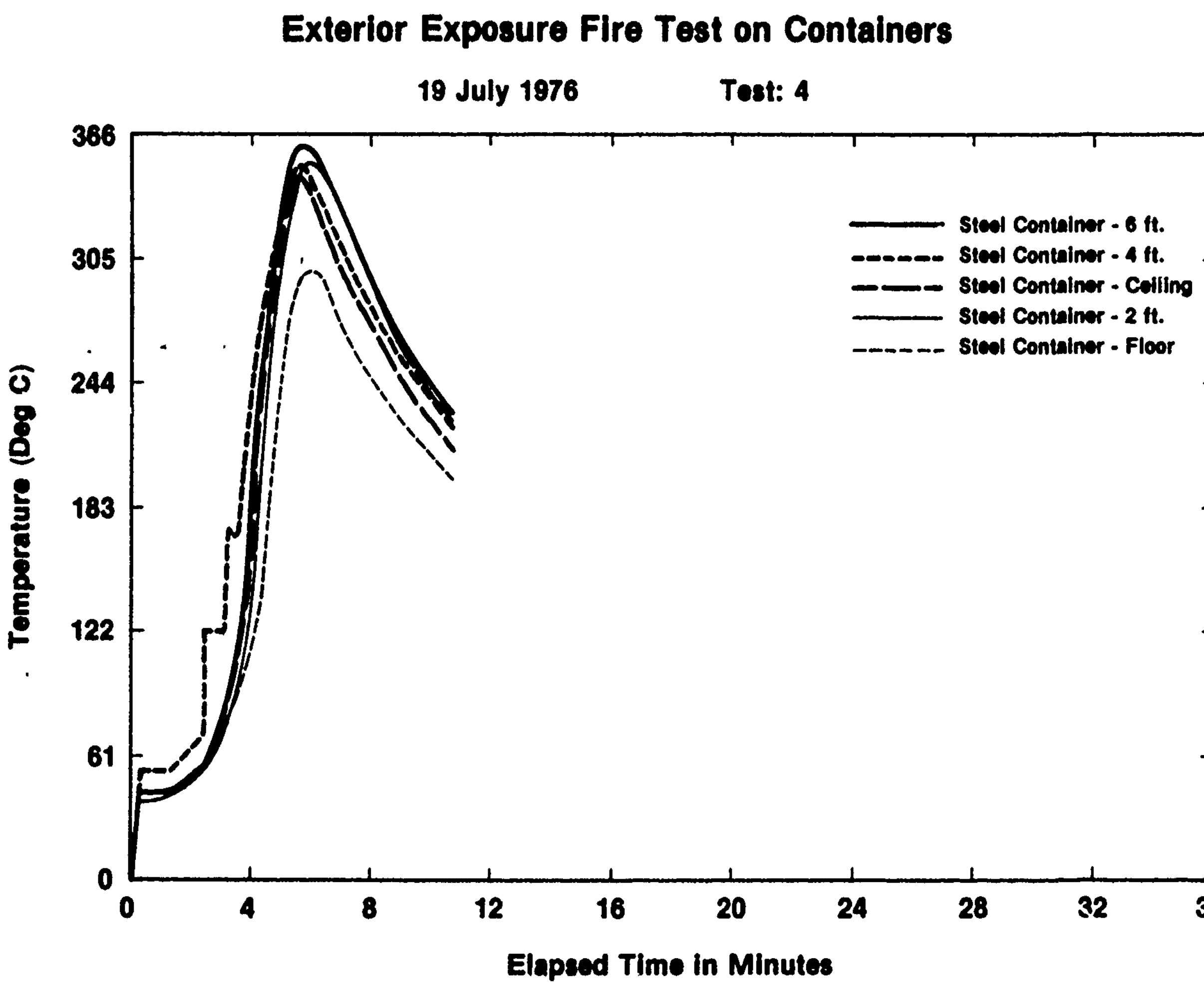

Interior Fire Test of Aluminum Container
19 July 1976
Test: 3a
Percent Carbon Monoxide
0
1
2
3
4
5
6
0
4
8
12
16
20
24
28
32
36
Elapsed Time in Minutes

APPENDIX B

EXTERIOR FIRE TEST DATA

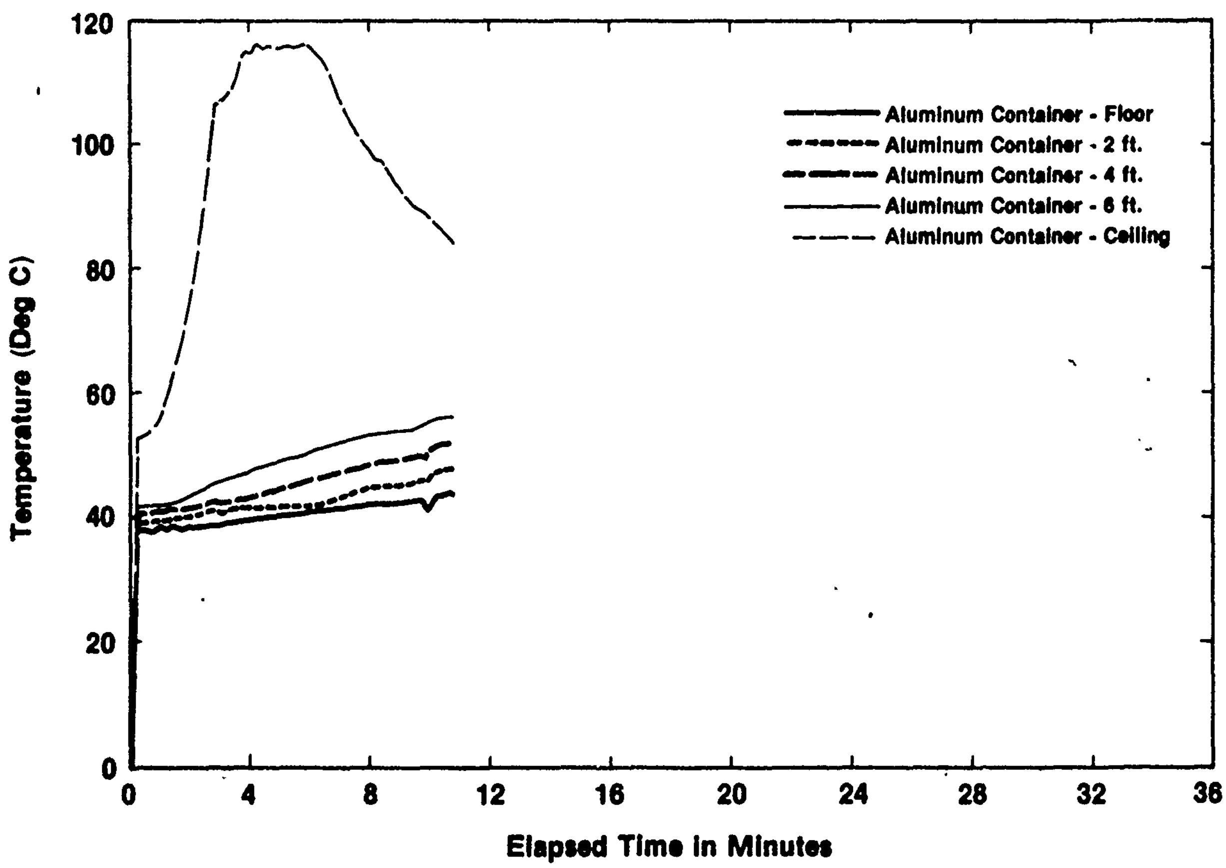
Appendix B
Container Construction Data - Three Level Array

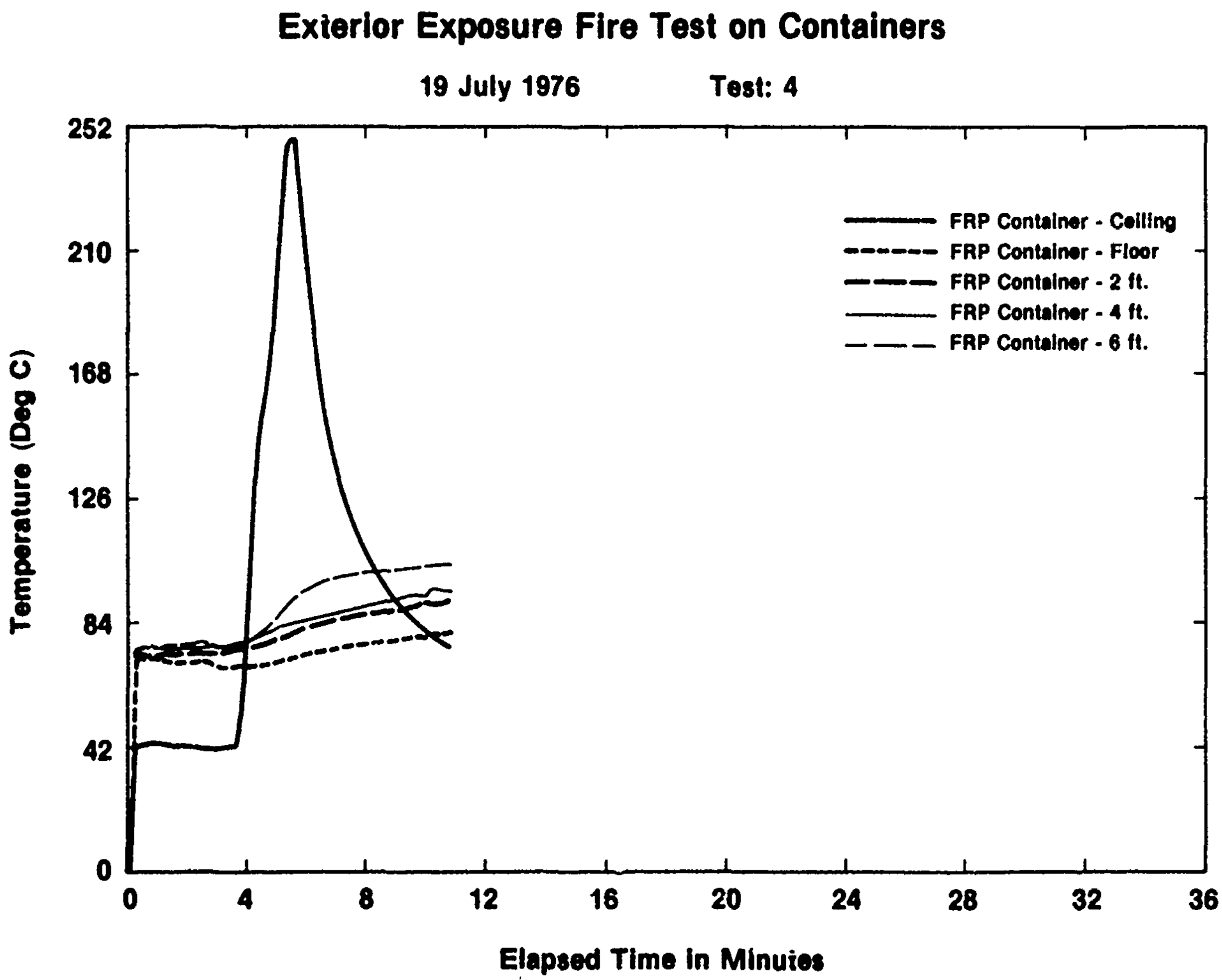
Container Number	Side & End Panels	End Frame, Front	End Frame, Rear	Top Rail	Bottom Rail	Roof	Doors	Floors	Lining
1. FRP 1966 Vintage	.06" Polyester fiber-glass sandwich-3/4" plywood core	6061-T6 or 6062-T6 Aluminum Alloy	Same	Same	Same	.06" polyester fiberglass sandwich 5/8" ply-wood core	N/A	N/A	N/A
2. Steel	Steel	High Tensile Strength Steel	Same	Same	Same	Steel	Steel	1 1/8" Oak	N/A
3. Aluminum Ex-terior Post 1966 Vintage	.063" Aluminum Sheet 1 3/10" Posts on 18" Ctrs.	High Tensile Strength Steel	Same	6061-T6 Aluminum Alloy	Same	.063" 3003-H14 Aluminum Sheet	3/4" ply-metal	1 1/4" hardwood tongue & groove	N/A
4. Aluminum Exterior Post 1966 Vintage	.051" Aluminum Sheet	High Tensile Strength Steel	Same	N/A	N/A	.050" Aluminum Sheet	3/4" ply-metal	1 1/4" hardwood	1/4" plywood 48" height
5. FRP	.06" Polyester fiberglass sandwich-3/4" plywood core	Aluminum Alloy	High Tensile Strength Steel	N/A	N/A	.06" polyester fiberglass sandwich-5/8" ply-wood core	plymetal Type 8P2	N/A	N/A
6. Aluminum	.063" Aluminum Sheet	High Tensile Strength Steel	Same	N/A	N/A	.063" Aluminum Sheet	1" ply metal	1 1/8" hardwood tongue & groove	N/A
7. FRP	SEE NUMBER ONE								
8. Aluminum	SEE NUMBER THREE								
9. Steel	SEE NUMBER TWO								


Exterior Exposure Fire Test on Containers
19 July 1976
Test: 4
Steel Container - 6 ft.
Steel Container - 4 ft.
Steel Container - Ceiling
Steel Container - 2 ft.
Steel Container - Floor
Temperature (Deg C)
366
305
244
183
122
61
0
0
4
8
12
16
20
24
28
32
36
Elapsed Time in Minutes

Exterior Exposure Fire Test on Containers

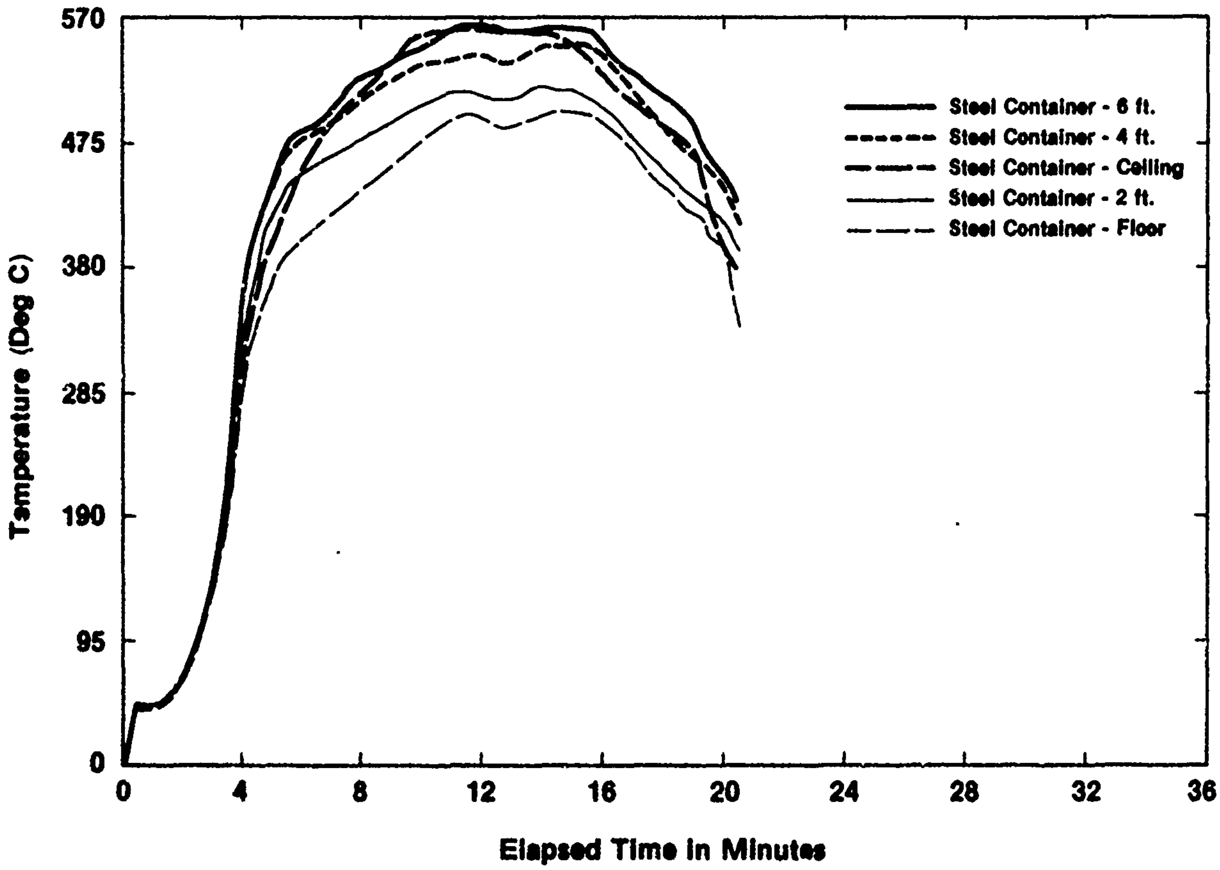
19 July 1976 Test: 4

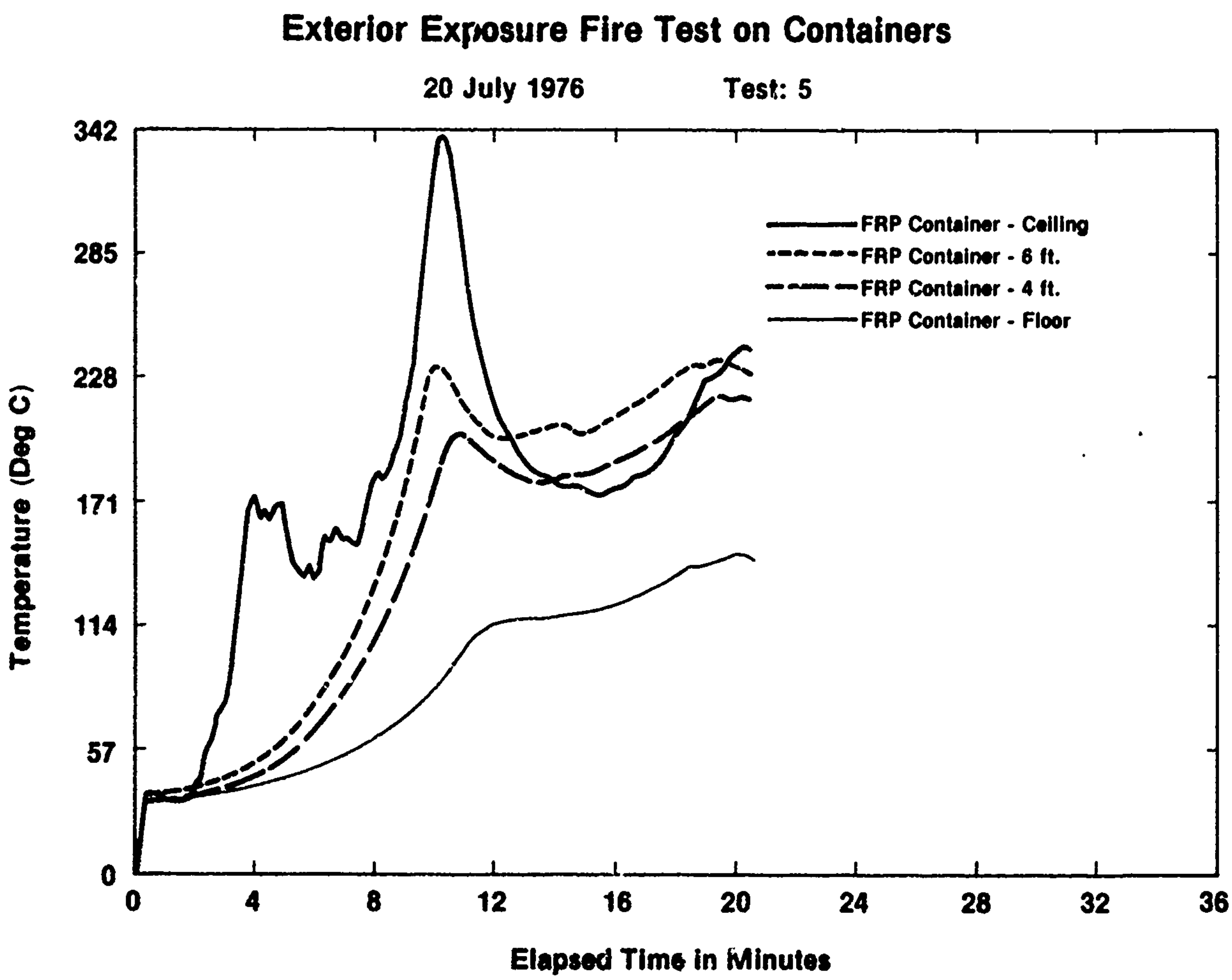



Exterior Exposure Fire Test on Containers
19 July 1976
Test: 4
Temperature (Deg C)
252
210
168
126
84
42
0
Elapsed Time in Minutes
0
4
8
12
16
20
24
28
32
36
FRP Container - Ceiling
FRP Container - Floor
FRP Container - 2 ft.
FRP Container - 4 ft.
FRP Container - 6 ft.

Exterior Exposure Fire Test on Containers

20 July 1976 Test: 5

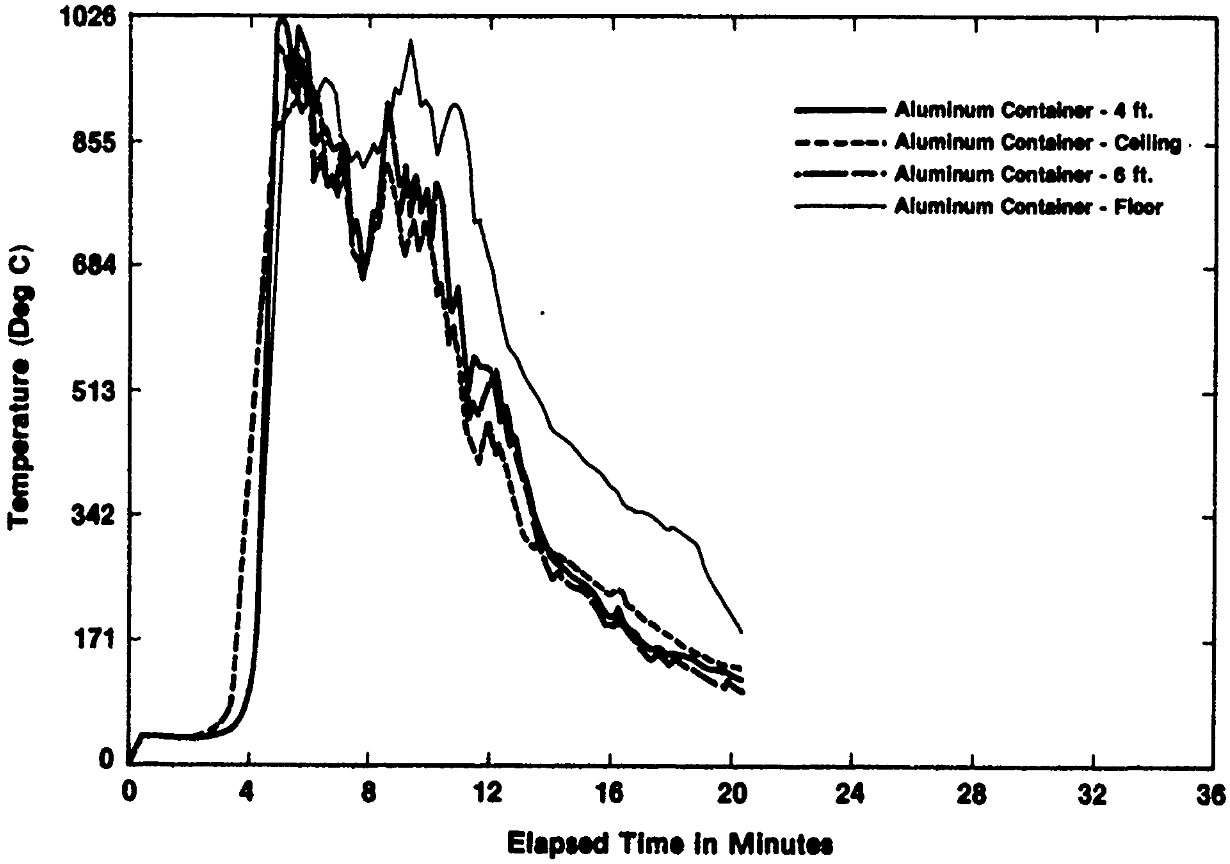




Exterior Exposure Fire Test on Containers
20 July 1976
Test: 5
342
285
228
171
114
57
0
Temperature (Deg C)
0
4
8
12
16
20
24
28
32
36
Elapsed Time in Minutes
FRP Container - Ceiling
FRP Container - 6 ft.
FRP Container - 4 ft.
FRP Container - Floor

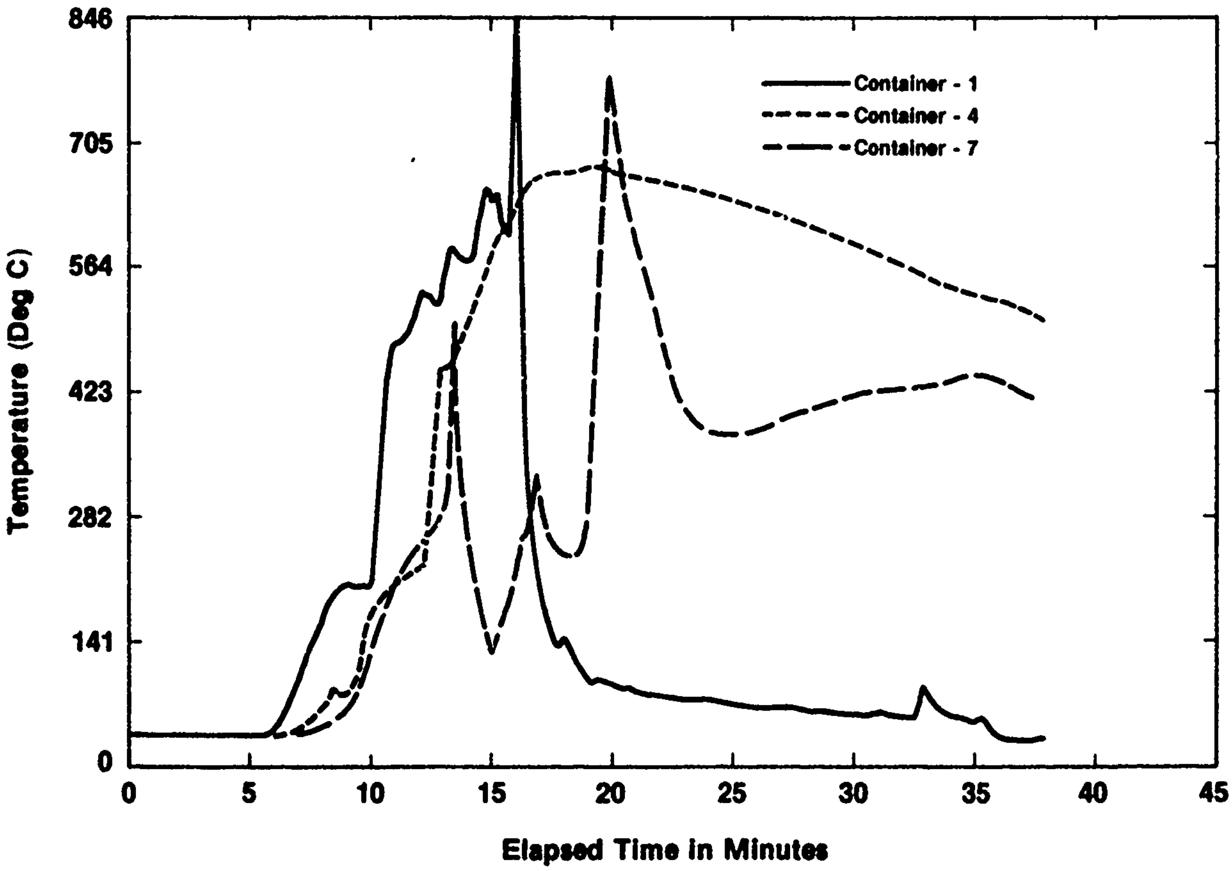
Exterior Exposure Fire Test on Containers

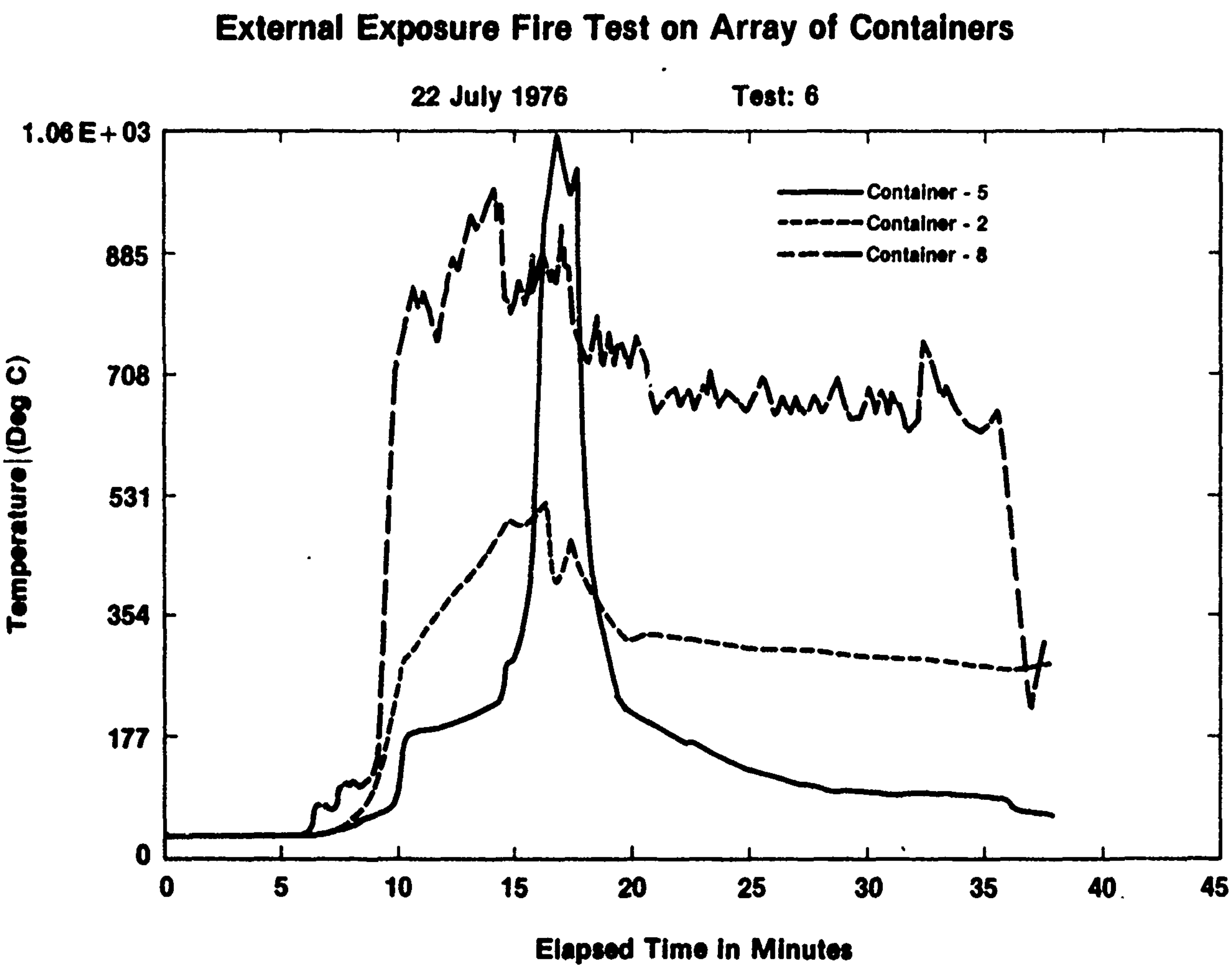
20 July 1976 Test: 5



External Exposure Fire Test on Array of Containers

22 July 1976 Test: 6




External Exposure Fire Test on Array of Containers
22 July 1976
Test: 6
1.06 E+03
885
708
531
354
177
0
Temperature|(Deg C)
Container - 5
Container - 2
Container - 8
0
5
10
15
20
25
30
35
40
45
Elapsed Time in Minutes

External Exposure Fire Test on Array of Containers

22 July 1976 Test: 6